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Time series modelling of the environmental factors affecting the daily catch rate of western rock lobster

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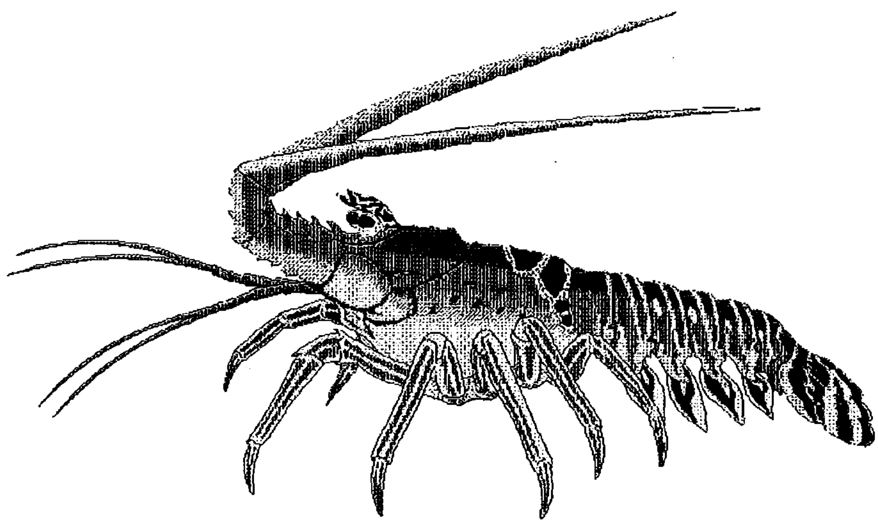

BY

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ABSTRACT

The western rock lobster fishery is one of the most significant and valuable single-species fisheries in Australia and in the world. It generates a gross commercial value of \$200-300 million dollars per year for the economy of Western Australia. The impact of environmental factors on the daily catch rate of the western rock lobster is of particular interest to the W.A. Marine Research Laboratories, at the Ministry of Fisheries, Western Australia. Considerable time and effort has been invested into building and developing suitable models to measure such impact on this fishery. While past research has focussed on monthly or seasonal data, this study investigated appropriate time series analyses to model the effect of major environmental factors such as lunar cycle, swell, and sea water temperature on the daily catch rate data of the western rock lobster at different depths. The variation in western rock lobster daily catch rate data for two periods ("whites" and "reds") and four categories (undersize, legal size, spawner, and setose), was examined for three management zones, A, B, and C. Regression and transfer function models for relationships between catch rates and environmental data were considered and compared.

Results show that the lunar cycle especially the presence of the full moon and the swell has a significant impact on the daily catch rates of the Western rock lobster. The results of this research assist in the development of improved models to support the management of this very valuable resource.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material.

Signature

Date....5.:..12.:..01............

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CHAPTER 1: *INTRODUCTION*

This thesis will focus on the influence of three environmental factors, lunar phase, swell, and sea water temperature, which affect the daily catch rate data of western rock lobsters. Appropriate time series models will be developed to describe the relationship between the environmental factors and the catch rates. Section 1.1 provides a brief overview of background information on the western rock lobster fishery, while section 1.2 discusses the significance of this research. The objectives of the study are included in section 1.3. In section 1.4 and section 1.5, the data sets and the computer software used in the research are respectively outlined. Finally, the structure of the thesis is presented in section 1.6.

1.1 Background

The fishery for western rock lobster (Panulirus cygnus) is Western Australia's most significant and valuable single-species fishery and has been a major source of economic income to the State. Over the last 20 years, Western Australia has produced annual rock lobster catches of about 10,500 tonnes per year which is worth between $200-300 million dollars (Fisheries Western Australia, 1999a). Due to the importance of the fishery, suitable management is needed for this resource to reach the best combination of ensuring biological sustainability and maximizing economic benefits.

The life cycle of the western rock lobster is complex. The eggs are hatched between November to February and the tiny larvae in this stage are called *phyllosoma*. During this period, the phyllosoma are carried by currents and winds to deep water off shore. The larvae stay at the phyllosoma stage for nine to 11 months, metamorphosing many times to increase their size. They grow to the final stage of larvae, called *puerulus*, when they are carried by currents and winds back to inshore reefs. It is at this stage that the larvae first resemble adult lobsters. (Phillips, 1975a, pp. 305-306).

According to Fisheries Western Australia (1999b), rock lobster larvae moult again and become juveniles within one or two weeks after their settlement in the continental shelf. Juvenile lobsters grow in these areas for 3 to 6 years. Every year, from November to January, some pale-coloured and recently moulted juveniles (called *whites*) migrate to deep water. In the course of their migration, these lobsters are vulnerable and large catches are taken by the fishery. Whilst in the deep waters, some juveniles moult to become adult and red. Maturity occurs one or two years after the migration. These mature and non-migrating lobsters are known as *reds* due to their colour. They support the catches made between February and June.

Rock lobsters reach the legal size for fishing when their carapace size is at about 77 mm between 15 November and 31 January or 76 mm between 1 February and 30 June. Rock lobsters generally reach their adult stage from between five to seven years and are then ready to reproduce. Mature female lobsters have setae or long fine hairs on forked structural appendages underneath their tails (one sign of spawning preparation). In this stage, they are called *setose*. After spawning, female lobsters carry the eggs underneath their tails with the help of the setae. This usually occurs between October to February. The mature females with the eggs are known as *spawners* (Fishing for Rock Lobsters: Fish for the future 1999/2000 season, 1999).

The western rock lobster fishing area in Western Australia extends from the southwest coast to the northwest cape. Figure 1.1(a) shows the distribution of the western rock lobster. The area is divided into three zones (See Figure 1.1(b)). Zone A is the area including the Abrolhos Islands and its surroundings, Zone B is the northern coastal area from North of Jurien to North of Kalbarri (21° 44' south latitude to 30° south latitude excluding the zone A), and Zone C includes the southern coastal area from Cape Leeuwin to the north of Jurien (30° south latitude to 34° 24' south latitude) (Moran, 1995).

Figure 1.1(a)

Figure 1.1(b)

(Source: Fisheries Western Australia, 1999c and 1999d).

Figure 1. 1: Distribution and fishing zones of the western rock lobster.

In Western Australia, several organisations are concerned with the impact of environmental conditions on fisheries' stock. One such institution is the government department, Fisheries Western Australia, which provides information by way of commercial fisheries production bulletins, fisheries management papers, fisheries research reports, brochures, and on-line information. The CSIRO Australia also provides valuable information in printed form and on-line.

1.2 Significance of Research

Catch rates from fisheries are used in stock assessment as an index of abundance. Hence, understanding the environmental factors affecting catch rates provides a way of standardizing these catch rate values. The impact of environmental conditions on the catch rates of fisheries stock has been investigated for the last few decades to provide improved stock assessment in several fisheries. Research in this area contributes to the more effective management of stocks. Work, in particular, has also been undertaken on the impact of environmental factors on the catch and vulnerability of western rock lobsters. Nevertheless, the majority of this previous research was carried out with weekly, monthly or yearly data. By focussing on daily data, the research will provide a better understanding of the environmental factors and their impact on the abundance of the western rock lobster.

This study is an extension of the research undertaken by Roberts (2000). Roberts used one environmental factor, lunar phase, to investigate variation in daily catch rates of legal size western rock lobsters at two different depths. Four phases of the moon (i.e. the new moon, the first quarter, the full moon, and the last quarter) were considered. Fishing seasons from 1993/1994 to 1997/1998 and the three main fishing zones were included in this study. The basic time series methods such as moving averages, classical decomposition, and the Holt-Winters method were also used to establish relationships between the lunar phase and the catch rates. Cyclic indices of the fishing seasons obtained from the Holt-Winters method were separated into two parts ("early" and "late" or "whites" and "reds" in this study) and compared with the lunar phase. Roberts' research demonstrated a significant relationship between the moon phase (especially the full moon) and the western rock lobster daily catch rates. In particular, it was shown that the catch rates decreased during the full moon. There is a need to extend this study to a more-detailed examination for the impact of the lunar cycle, swell, as well as sea water temperature and to develop appropriate stochastic models.

The research described in this thesis extended Roberts' work. The original plan was to use catch rates of all four categories of western rock lobsters, that is, legal size, undersize, spawner, and setose rather than just the catch rate data of legal size lobsters. However, due to the problems from big gaps of missing data and lack of catch rate data for spawner and setose lobsters, the catch rates for spawner lobsters were ignored, and the catch rates for setose lobsters in only a few fishing seasons and some appropriate zones were used. Data were also used from the two lobster stages, whites and reds.

Moreover, this research incorporated a wider range of environmental factors than that of Roberts. For example, it focused on the impact of three environmental conditions (i.e. lunar cycle, swell, and sea water temperature) on the western rock lobster's daily catch rates. These environmental conditions were selected, as there is evidence from previous localised studies of the impact on rock lobster catch rates. The cyclic pattern of the catch rates, after removing the trend (i.e. the change in the mean level over the daily catch rate data), was investigated in the three lobster categories and the two stages of lobsters. The research was carried out in all three fishing zones and at different depths of water. In addition, suitable models were fitted to the relationships between the environmental factors and the daily catch rates. The research therefore improves on some of the current time series models used in the management and stock assessment of the western rock lobster fishery.

1.3 Purpose of the study

The purpose of this study is:

(1) To examine the influence of lunar cycle, swell, and sea water temperature on the daily catch rate of the three rock lobster categories (legal size, undersize, and setose) from the three fishing zones (A, B and C) by using appropriate time series analysis.

(2) To develop appropriate time series models to relate the daily catch rate to the environmental variables.

(3) To provide better models to further the understanding of stock and recruitment for the western rock lobster in order to enhance the management of the stock.

1.4 Data Sets

Data sets used in this research consist of two main parts, the daily catch rate data and the data for the three environmental factors (lunar phase, swell and sea water temperature). Section 1.4.1 provides information on the source and the detail of the daily catch rate data, while section 1.4.2 considers those of the environmental data.

1.4.1 Daily Catch Rate Data

The daily catch rate data for this thesis were obtained from the Western Australian Marine Research Laboratories (WAMRL), Department of Fisheries (Western Australia). The raw data were derived from the Fisheries Research database of voluntary daily logbook entries collected from professional fishers. These logbooks were completed by about 35-40% of the fleet of about 600 vessels. The data sets consist of seven fishing seasons from 1992/1993 to 1998/1999. Data sets for each season are composed of catches (kilograms) of legal size lobsters and catches (numbers of lobsters) of undersize, setose, and spawner lobsters (at five different depths (0-10, 10-20, 20-30, 30-40, and > 40 fathoms)) in the three major fishing zones. In addition, information on the number of pot lifts and soak time was obtained. Permission has been sought from the W.A. Marine Research Laboratories to use the data from these logbooks and to present results of summarized data in this research.

The fishing season in Zone A is shorter than that in Zone B and Zone C because it starts in March instead of November as that in the other two zones. In addition, each fishing season in Zone B and Zone C was separated into two parts. The first part or the early season starts from the middle of November to the end of January and coincides with peak catch rates for whites. The second part or the late season, where catches of reds predominate, starts in February and extends until the end of June.

The catch rates are generally based on 24-hour soak time. However, the raw data include many days where there are two or more days between pulling the pots. This is because some pots were left in the water for more than one day. In this case, it is hard to tell the day that the catch occurred. Thus, only the data from one day pulls were only considered in this study. In order to obtain the daily catch rates, the catch was divided by the number of pot lifts for each day. This can be defined as the equation below:

$$\text{Daily Catch Rates} = \text{Catch} / \text{Number of Pot Lifts}$$

For legal sized lobsters (including whites and reds), catch rates from the five different depths were collapsed into two groups: (1) depths of 0-20 fathoms or shallow water; and (2) depths of > 20 fathoms or deep water, in order to provide a manageable number of the data sets for this study. Moreover, as it was noted that most undersized lobsters stay at a depth of 0-10 fathoms, while most setose and spawner lobsters have their major habitat at a depth of 20-30 fathoms, this research thus focuses on these two depths for each specific category of lobsters.

Nevertheless, there were some problems with missing data in the daily catch rates especially those in the data of setose and spawner lobsters. There were many big gaps of missing data in the catch rates, and not enough data were recorded for these two categories. Consequently, it was decided that the catch rates of spawner lobsters would not be further investigated, and only the catch rates of setose lobsters for the season 1992/1993 in Zone C, the season 1993/1994 in Zone A, the season 1995/1996 in Zone C, and the season 1996/1997 in Zone C would be studied because there were not too many missing values in these series. The particular data of setose lobsters were used after the missing values were estimated by a software package called STAMP[1]. Likewise, gaps of missing values appeared in some catch rate data of legal sized and undersized lobsters, but most of these missing values could also be predicted by STAMP. However, STAMP could not handle missing data especially big gaps in values for some of the catch rates, so such data were also discarded. Table 1.1 provides the daily catch rate characteristics showing the number of days of observations available for each of the 55 data sets considered in this thesis.

[1]STAMP or Structural Time Series Analyser, Modeller, and Predictor is a computer software package with two programs. One is a special version of the system for time series facilities for the management of the data sets. The other one performs the estimation and testing of structural time series models.

Table 1. 1: Daily catch rate data characteristics including the number of days for all data sets considered in the research.

Season And Zone		Lobster Categories			
		Legal size		Undersize	Setose
		Shallow	Deep		
92/93	Zone A	108	108	108	-
	Zone B	-	-	-	-
	Zone C	228	228	228	194
93/94	Zone A	108	108	108	107
	Zone B	228	228	228	-
	Zone C	228	-	227	-
94/95	Zone A	108	-	107	-
	Zone B	228	228	228	-
	Zone C	-	-	-	-
95/96	Zone A	108	108	104	-
	Zone B	229	229	229	-
	Zone C	229	229	229	215
96/97	Zone A	108	108	108	-
	Zone B	228	228	228	-
	Zone C	228	228	-	205
97/98	Zone A	108	108	108	-
	Zone B	228	228	228	-
	Zone C	228	228	-	-
98/99	Zone A	106	106	103	-
	Zone B	228	228	-	-
	Zone C	228	228	-	-

1.4.2 Environmental Data

The data for the three environmental factors (i.e. lunar phase, swell, and sea water temperature) were obtained from different sources. The data of lunar cycle were obtained from the Bureau of Meteorology or from the internet site of the Australian Surveying and Land Information Group (AUSLIG). The swell data came from voluntary daily logbooks summarised by the W.A. Marine Research Laboratories of Fisheries (Western Australia) while the water temperature data were available from the commercial length-monitoring program of Fisheries (Western Australia).

The lunar cycle obtained from AUSLIG was recorded in four phases of the moon, which are new moon, first quarter, full moon, and last quarter. At the new moon phase, the moon does not appear to be illuminated. This phase happens when the apparent longitudes of the moon and sun are not different. The first and last quarter phases occur when the apparent longitudes of the moon and sun differ by 90 and 270 degrees, and 50 percent of the moon's visible surface is illuminated at these two phases. The full moon phase is the time when the apparent longitudes of the moon and sun differ by 180 degrees, and the moon is visible 100 percent. (Commonwealth of Australia, AUSLIG, 2000b). The data were recorded in terms of hour, minute, day, month, and year (in this study only the data from 1992 to 1999 were used) when the moon phases occurred in Australian Eastern standard time. To calculate in terms of Western standard time, two hours were therefore deleted from every record of the data.

Raw swell data obtained from the original logbooks were recorded in the form of a rank from 0 to 3 in increments of 0.5. Higher numbers indicate the stronger conditions of the swell on the recorded day. However, the data prepared by WAMRL are the average numbers of all swell data recorded in the original logbooks on the same days. In addition, there were a few missing data of swell, so again STAMP was used to estimate these values.

Sea water temperature data were only available for the three-year period 1992 to 1994 at seven different sites, which are Rat Island, South Passage (Shark Bay), Seven Mile Beach, Jurien, Alkimos, Warnbro Sound, and Cape Mentelle. From the positions of temperature loggers used for recording the data (See Appendix A), the data at Rat Island were representative of Zone A, the temperatures at South Passage and Seven Mile Beach were used for Zone B, and the values at Jurien Bay, Alkimos, Warnbro Sound, and Cape Mentelle were used for Zone C.

However, recording sea temperatures is a complex task. Although loggers are used for recording, some problems from unreliable or broken loggers do occur. This resulted in some lengthy gaps in the data at some sites. Thus, only suitably continuous sea temperature data were selected for investigation.

1.5 Computer Software

Various software packages are required to provide outcomes at different steps of the research. Minitab and Excel were used for data handling and graph constructing.

STAMP was applied to handle missing values in any series. To calculate moving averages and centred moving averages, Excel was used. Minitab was also used to analyse the results in terms of time series. The program TSA[2] was used to generate spectrums[3] of the data sets. SPSS was used to generate cross correlations. In addition, Scientific Computing Associates (SCA[4]) was exploited for regression and transfer function modelling.

1.6 Structure of the Thesis

This thesis is presented in several parts. Literature review related to relevant research on the western rock lobster and other species is provided in chapter 2. It is assumed in this study that readers have basic knowledge in time series analysis. However, chapter 3 briefly describes the mathematical methods used in the research such as moving averages, cross correlations, classical decomposition, Holt-Winters method, ARIMA models, multiple regression models, and transfer function models. Results corresponding to effects of environmental factors on the catch rates are shown in chapter 4 while results of time series modelling are given in chapter 5. In conclusion, chapter 6 discusses and summarizes the results given in previous chapters. Future research directions are also provided in this chapter.

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[2] TSA is a software package for the analysis of time series models.

[3] Spectrums or spectral density functions are a tool for data analysis. Each spectrum provides the distribution of the variance in a process at different frequencies (measured in radians). A peak in the spectrum can be used to refer to a cycle in the process.

[4] SCA is a statistical system providing a variety of statistical analyses created by Scientific Computing Associates. It is appropriate for both routine data analysis and statistical research.

CHAPTER 2: *LITERATURE REVIEW*

Environmental factors have been viewed for many years as having an important impact on fisheries stock. Much research has been undertaken in this area, and that which relates environmental factors to fisheries stock is reviewed in this chapter. For example, the impact of the four moon phases on catch rates of the western rock lobster studied by Roberts (2000) was outlined in section 1.2, chapter 1. Other studies relating to the influence of environmental conditions on the western rock lobster catch rates are described below in section 2.1. Section 2.2 shows similar research with other marine species. Finally, section 2.3 provides a summary of literature review.

2.1 Research with the Western Rock Lobster

Limited research has been undertaken on the environmental factors which have an impact on catches of western rock lobsters. For instance, Phillips (1975b) examined the effects of water currents and moonlight intensity on daily catches of the rock lobster larvae at Seven Mile Beach in Western Australia, a site of shallow (depth from one to five metres) coastal limestone reefs and sea grass beds. Phillips used collectors composed of artificial seaweed in his research. Since the puerulus larvae settles on the collectors during the night, water currents were measured by summarizing the flow rate as recorded at each hour from 1800 hours to 0600 hours (relative overnight flow) using a moored current meter. This meter was located inside the reef area adjacent to the collectors. The intensity of moonlight was estimated at each hour for each night and recorded as a percentage of the moonlight intensity from the full moon as its zenith. Phillips found that the water currents had no significant relationship to the monthly lunar settlement of the puerulus larvae and the number of puerulus larvae settling on the collectors. The results showed that there was no evidence of any patterns between the relative overnight water flow and the lunar cycle or the catches. However, Phillips did find a relationship between catches of puerulus and moonlight intensity. For example, most puerulus settlement begins with the dark phase of the moon and ceases at the beginning of a new moon period when the moonlight intensity is near to 10 percent of full moonlight.

Morgan (1974, 1977) studied the relationship between three conditions (i.e. sea water temperature, water salinity, as well as the moulting activity) and monthly catches of western rock lobsters at Rat Island in Zone A. The study site had a depth of six to 10 metres with coral and limestone reefs scattered with some sand patches. The catch and effort used in this research were made at the time of new moon from November 1969 to March 1973. The temperature data, the salinity data, and the premoult data during this period were recorded in terms of the degree Celsius, the percentage of water salinity, and the percentage of rock lobsters in a premoult condition respectively. Morgan found that water temperature and salinity had a positive correlation with catchability while the percentage of lobsters in a premoult condition had a negative correlation with the catchability coefficient. A linear model of the three factors and the catchability coefficient also showed a strongly correlated relationship which can be defined in the equation: $q \times 10^3 = -315.17 + 0.54T + 8.80S - 0.71P$, where q is the catchability coefficient, T is the bottom temperature, S is the salinity and P is the percentage of rock lobsters in a premoult condition. In addition, it was noted in this study that there was no significant difference in the percentage of rock lobsters in a premoult condition throughout the size range. Therefore, if the linear model mentioned before holds for all size groups, no difference in catchability should occur.

The relationship between indices of juvenile abundance and recruitment in the western rock lobster fishery was investigated by Caputi and Brown (1986). Juveniles considered in this study were three and four years old. The year-classes of the western rock lobster here were recorded by the time of hatching, and 11 year-classes from 1968-69 to 1978-79 were available for the examination of the relationships between juveniles and recruits to the fishery. The year-class 1979-80 was used to forecast the latest recruitment. The indices of juvenile abundance were based on length frequency data obtained from a commercial monitoring program. The calculation for the index was made from a step-wise multiple regression of logarithmically transformed juvenile catch rates with other variables such as year, month, location, sublocations, depth, soak time, and moonlight. The results indicated that the factors, depth and location, have the biggest effect on the catch rate variation with the decreasing catch rates from northern to southern locations and from shallow to deep water. In addition, catch rates decrease slightly with the increasing soak time of the pots and during the full moon. Catch rates after taking logarithmical transformation in depths of 0-18 metres and using only pots with one day soak time were used for estimating a revised index of recruitment. To smooth out daily fluctuations in the catch rates, a 7-d moving average was undertaken on the data. The recruitment index was taken from the highest back-transformed 60-d value during the recruitment time from November to January. The relationships between the indices of 3-year-old and 4-year-old male juveniles (JM_3 and JM_4) and the revised recruitment index (*RRI*) respectively have the correlations of 0.95 and 0.93. These relationships can be described as following equations: $RRI = 0.7676 JM_3^{0.8618}$ and $RRI = 0.6372 JM_4^{0.4991}$. The multiple regression showing how 3-year-old and 4-year-old juvenile indices can predict the recruitment in the same year-class is given as the following equation: $RRI = 0.7072 JM_3^{0.5341} JM_4^{0.2223}$. The correlation for the previous model is 0.97.

More recently, Caputi, Brown, and Phillips (1995) have developed an improved way to predict catches of the western rock lobster by combining indices of puerulus and juvenile abundance together. The index of puerulus settlement was estimated from the level of settlement measured using artificial seaweed collectors at Seven Mile Beach and Jurien Bay. The total catch can be predicted by the puerulus settlement data with a correlation of 0.88 as the following equation: $Catch_t = 3.51 P_{t-3,t-4}^{0.245}$, where $P_{t-3,t-4}$ is an average of the puerulus abundance three and four years prior. The index of juvenile abundance was calculated using the same method as in Caputi and Brown (1986). However, the data here were monthly data of 4-year-old undersized lobsters obtained from four different areas, Dongara, Jurien Bay, Lancelin, and Fremantle. The two moulting periods in a fishing season, whites (November-January) and reds (February-June), were also considered in the study. The logarithmically transformed equation with a correlation of 0.97 fitted to the relationship between the catch during the period of whites and the juvenile index for the previous season ($J1_{t-1}$). Thus, the puerulus abundance index four years earlier is: $Whites_t = 11.7 P_{t-4}^{0.112} J1_{t-1}^{0.602} \exp(0.327 EG)$, where *EG* stands for escape gaps. For the period of reds, the catch is related to the puerulus abundance 3 years before instead of 4 years, so the equation with a correlation of 0.87 can be defined as: $Reds_t = 7.08 P_{t-3}^{0.081} J2_{t-1}^{0.210} \exp(0.299 EG)$. The equation for the total catch is: $Catch_t = 22.9 P_{t-3,t-4}^{0.071} J12_{t-1}^{0.445} \exp(0.367 EG)$, where $J12_{t-1}$ is an average of the juvenile indices in the previous season for both periods of whites and reds. It is the combination between the model for whites and the model for reds with a correlation of 0.95. Therefore, the puerulus index has a long-term relationship (up to four years) with the catch while the juvenile index of a year before can be used to forecast the catch. These predictions are useful in terms of management for the fishery.

Caputi, Fletcher, Pearce, and Chubb (1996) have shown that the Leeuwin Current, the principal ocean current off the coast of Western Australia, has a positive effect on annual rock lobster larvae or puerulus settlement in the inshore coastal areas. The influence of the Leeuwin Current strength was measured by using the Fremantle sea level for the calendar year (January to December). The results indicated a reliable pattern of the correlation between the monthly variation in the Leeuwin Current and the annual puerulus settlement with a peak in April, a decline in June, and another peak in August or later, which is during the time of the puerulus settlement (September to January). These outcomes provided a consistent pattern for the settlement at Garden Island in the 1970s, at Alkimos and Cape Mentelle since the early 1980s, and at Dongara, Jurien, and Abrolhos Islands over both periods. In conclusion, the Leeuwin Current may have two effects on the puerulus settlement. First, a stronger current combined with higher temperature in April probably increases the growth and survival of the puerulus larvae. Second, the current could help the preservation of the puerulus larvae by eddies and support the transportation of the later stages of the larvae across the continental shelf into the coastal reefs (nursery areas).

According to Farag (1998), westerly winds in the southern locations and the Leeuwin Current have a positive influence on the puerulus settlement at Dongara and Alkimos, Western Australia. In addition, westerly winds in the northern locations have a negative impact while spawning stock has a positive impact on the puerulus settlement at the Abrolhos Islands, Western Australia. The puerulus settlement data from 1968/69 to 1992/93, from 1982/83 to 1992/93, and from 1971/72 to 1992/93 were used for the investigation at Dongara, Alkimos, and the Abrolhos Islands respectively. The mean Fremantle sea level in this study was used to represent the Leeuwin Current strength, and rainfall was used as the index of the western winds. Four different models (i.e. a multiple regression model, a transfer function model, a linear growth model, and a multiple regression model with ARIMA disturbances) were fitted to the relationship at each area considered. Results from this study indicated that the multiple regression models with ARIMA disturbances for the relationships in all three locations provide better fits than the other models.

2.2 Research with Other Species

Related research has focused on the impact of environmental factors on other marine species. For example, Draganik and Cholyst (1990) have analysed the effect of water temperature and moonlight on the catch rates for swordfish. Data of the vertical distribution of 306 swordfish, Xiphias gladius L., caught by long-lining in the area between 2-16 degree N latitude and 19-31 degree W longitude in 1983 were examined. The catch rate was considered in terms of catch in kg per 100 hooks. Results indicated that high catch rates have corresponded to high temperatures and the full moon period.

Matsuda and Yamakawa (1997) studied the effects of temperature on growth of the phyllosomas of the Japanese spiny lobster or Panulirus japonicus, one of the most significant assets and profitable fisheries in Japan. The phyllosomas used in this study hatched from six females between 1995 and 1996. Temperature trials were separated into six different groups by the body length of the phyllosomas. Trials 1-4 were managed for the small and medium-sized phyllosomas (1.5-3.5 mm, 1.5-14.1 mm, 6.0-13.6 mm, and 14.5-18.4 mm) while trials 5 and 6 were used for the large phyllosomas and larvae in the puerulus stage (17.6 mm and 17.7 mm to larvae in the puerulus stage). These phylosomas were reared at one of four water temperatures (i.e. 20°, 22°, 24°, and 26°C). The research shows that increasing temperature can be correlated with the increasing intermoult period and the decreasing moult increment. Nevertheless, the opposite results occurred with medium and large phyllosomas at 26°C. The best temperature for growth, which seemed to be the optimum temperature for survival, decreased from 26° to 24°C at 15 mm body length.

Considerable research has been undertaken on the environmental impact on prawn populations. For instance, White (1975) found that the light-dark cycle, moon phase, and seasonal or annual change in water temperatures affected the catch per unit of effort or the catch rate of the Tiger prawn (Penaeus esculentus) in Exmouth Gulf, Western Australia. The catch per unit of effort for the fishing seasons 1969, 1970, and 1971 was investigated. It was found that the optimum catches are made during night hours. The highest catch occurred in the period just before the full moon phases, and the lowest catch happened during the new moon phases. Moreover, the catch per unit of effort began to decrease at the beginning of every season and declined to a minimum at the end of July. However, it increased again after that or early August when the temperature began to rise. Catchability was at a maximum at the time of maximum temperature. Long-term changes in catchability might be correlated with the water temperature while short-term changes were probably related to the lunar cycle. Some mathematical models were fitted to explain the relationship between the catch per effort and the two environmental factors, water temperature and lunar cycle.

Penn and Caputi (1985) have demonstrated some factors affecting the abundance of Tiger prawns in Exmouth Gulf. The interaction between the stock to recruitment relationship (SRR) including some environmental factors and the alternate recruitment to spawning stock relationship (RSR) for the Tiger prawn stock has shown that the mix of general environmental conditions and high levels of effective effort in the post-1979 period was responsible for the fivefold decline in catch from 1980 to 1982. Data of the daily catch (tonnes) and the effort in Exmouth Gulf from the 1963 fishing season to the 1984 fishing season obtained from research logbooks were investigated. Summer and autumn tropical cyclones were found to have both positive and negative effects on stock recruitment for Tiger prawns in the Exmouth Gulf. Cyclones creating heavy rainfall have a negative influence on small juveniles in shallow water or nursery areas, but they have the positive effect on lobsters in deep water because the increased turbidity from cyclones decreases predation. Some models were fitted to describe the relationship of the stock recruitment, the recruitment spawning stock, the effective effort on recruits, and the rainfall (from the cyclones mentioned before).

According to Courtney, Die, and McGilvray (1996), there is an interaction between the catch rates, lunar phase, and the sex ratio among adult eastern King prawns, Penaeus plebejus, in relatively deep (160 metres) coastal waters off south-eastern Queensland. The catch rate data used in this research were obtained from a compulsory logbook program from 1 May to 31 July 1993 and a research sampling program from 24 May to 21 July 1993. An interaction was found between lunar phase and sex of prawns. Females dominate catches, but males dominate peaked catches during the three days before and after the full moon when the sex ratio is equal to 1:1. Likewise, the trawl-time also had an interaction with sex. Early in the evening, the catch rates of males were at a minimum while those of females were at a maximum and then declined during the night. A cyclic regression was fitted to the occurrence of mature females. The explanatory variables in the regression were time (in days after the first new moon phase) and time of night (trawl-time).

Furthermore, Cross, Fernandez, Caputi, and Watson (1999) have examined the impact of the moon phase on the catch rate for the western king prawn, Penaeus latisulcatus, the Brown Tiger prawn, Penaeus esculentus, and the Blue Endeavour prawn, Metapenaeus endeavouri, in Exmouth Gulf and Shark Bay. Monthly data for six years of commercial catch and effort from 1972 to 1987 were used. Results showed that catch rates of the western king prawn in Exmouth Gulf and Shark Bay and those of the Blue Endeavour prawn in Exmouth Gulf decreased during the full moon period. On the other hand, there was no reduction in catch rates of the Brown Tiger prawn in both Exmouth Gulf and Shark Bay during the full moon.

2.3 Summary of Literature Review

The preceding research reviewed in sections 2.1 and 2.2 provides evidence that lunar cycle or light intensity and sea water temperature have impacts on the catch, the catch rate or the abundance of several marine species. As a result, it is worth investigating the effect if any of lunar cycle and sea water temperature on catch rates of the western rock lobster. On the other hand, no previous studies were mentioned in this chapter about an impact of swell on catchability of any fisheries because not much research has been undertaken in this area. However, swell will be investigated as an environmental factor affecting the catch rates in this thesis since there is some evidence from the fishers that swell may also have an influence on the catch rates.

CHAPTER 3: *MATHEMATICAL BACKGROUND*

For decades, mathematicians and researchers have used time series as one of the most efficient techniques for modelling time related data. There is abundant research in this field. Research which addresses time series techniques relevant to this study include Bennett (1979), Box & Jenkins (1976), Bowerman & O'Connell (1987), Brockwell & Davis (1991), Brockwell & Davis (1996), Chatfield (1996), Cryer (1986), Hanke & Reitsch (1998), Kendall & Ord (1990), Janacek & Swift (1993), Makridakis, Wheelwright, & McGee (1983), Newbold & Bos (1990), Harvey (1981), Harvey (1989), and Vandaele (1983).

The following sections briefly describe the relevant background to time series analysis and methods for applying this mathematical background to provide research results. Section 3.1 presents the use and calculations of moving averages, including centred moving averages while section 3.2 gives the summary of cross correlations. Classical decomposition is discussed in section 3.3. Holt-Winters method is introduced in section 3.4. Box and Jenkins models, ARIMA as well as SARIMA, are considered in section 3.5. Section 3.6 briefly discusses regression models with and without the term of ARIMA errors. Finally, section 3.7 deals with the introduction of transfer function models.

3.1 Moving Averages and Centred Moving Averages

Moving averages and centred moving averages are used to smooth data or eliminate seasonal effects and irregular fluctuations (residuals or random noise components) from observed series. The weighted moving average at the order i of a time series with n observations can be defined by the following formula.

$$X_i' = \sum_{j=i}^{m+i-1} w_j x_j \qquad ; i = 1, 2, \ldots, n-m+1 \qquad (3.1)$$

where $x_1, x_2, x_3, \ldots, x_n$ are n observations in a discrete time series.

$\{w_j\}$ is a set of weights.

m is the number of observations used for each moving average.

The most common method of moving averages is called single moving averages, which occurs when $w_j = \frac{1}{m}$. Moreover, if the set of weights is selected carefully, seasonal or cyclical effects can be eliminated. Weighted moving averages such as Spencer and Henderson moving averages are useful for this purpose with monthly data.

If a time series is based on m which is an odd number, centred moving averages are unnecessary because each moving average at the order i corresponds to the time at the order $\frac{m+1}{2}+i-1$ in that time series. However, most time series have daily, monthly, or quarterly data (m is an even number in this case), so centred moving averages are calculated to obtain more accurate results. The centred moving average can be defined using the equation given below:

$$X_i^{''} = \frac{X_{t+i-1}^{'} + X_{t+i}^{'}}{2} \quad ; i = 1, 2, \ldots, n-m \text{ and } t = \frac{m+1}{2} \tag{3.2}$$

More information about this method available from Chatfield (1996), Makridakis, Wheelwright, and McGee (1978), and Bowerman and O'Connell (1987).

To examine the influence of the lunar cycle, the swell, and the sea water temperature on the daily catch rate of western rock lobsters, the trend in the daily catch rate data was removed by using centred moving averages. This was undertaken to eliminate the influence caused by the trend. In addition, the trend was used to identify the relationship of the water temperature on the catch rates. The program Excel can be used for this purpose. Figure 3.1 shows the original catch rates, the smoothed trend (centred moving average) , and the detrended catch rates (catch rates after removing the trend) for the 1998/99 fishing season at the depths of 0-20 fathoms in Zone C.

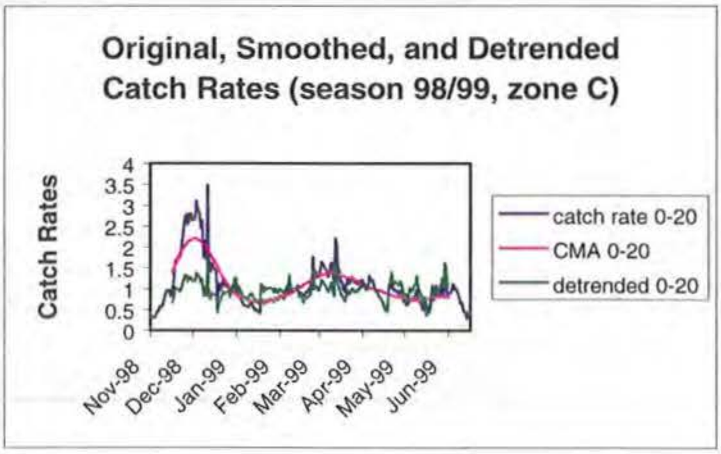


Figure 3. 1: Original catch rates, smoothed trend line, and detrended catch rates for the 1998/99 fishing season at the depths of 0-20 fathoms in Zone C.

Here the number of observations used for each moving average (m) was chosen to be 30 because there appeared to be a cycle of approximately 30 days in the data. The research undertaken by Roberts (2000) supports this understanding. Therefore, centred moving averages need to be computed after calculating moving averages. The graph of centred moving averages in Figure 3.1 illustrates the smoothed series of the original catch rates without m observations at the start and the end of the series.

According to Robert (2000), the time series for the original catch rates is considered to be multiplicative. The detrended catch rates thus can be calculated by using the following equation.

Detrended Catch Rates = Original Catch Rates / Centre Moving Averages (3.3)

The time series plot of the detrended catch rates for shallow water of the 1998/99 season in Zone C are shown by the green line in Figure 3.1. This line illustrates the cyclical pattern of the data after removing the trend.

Weighted moving averages for the catch rate such as Henderson moving averages were considered in this thesis. According to Kenny and Durbin (1982), the coefficients or the weights of a symmetric moving average of length $(2n + 1)$ as $\{c_k, k = -n, \ldots, n\}$ can be approximately defined as the following equation.

$$c_k = \{(m+1)^2 - k^2\}\{(m+2)^2 - k^2\}\{(m+3)^2 - k^2\}\{3(m+2)^2 - 16 - 11k^2\} \quad (3.4)$$

However, none of the Henderson moving average has been undertaken on daily series. The options for length of Henderson moving averages are normally 9, 13, and 23 terms for smoothing monthly data and 5 terms for smoothing quarterly data. The choices of 7, 15, and 17 term Henderson moving averages are also available for this set. For instance, Castles Report (1987, p. 37) found that:

"To smooth monthly seasonally adjusted series the Australian Bureau of Statistics uses a cost effective procedure that is an integral and major part of its seasonal analysis process. The filter used is generally the 13 term Henderson moving average, which is known to have certain desirable time series characteristics..."

Thus, the 31 term Henderson moving average was chosen with the hope that it would remove cycles of the length 30 in the daily catch rates. The symmetric coefficients for this moving average were computed. These values are as follows (ending with the middle term): –0.002, –0.005, –0.009, –0.012, –0.012, –0.009, –0.002, 0.009, 0.023, 0.039, 0.056, 0.073, 0.088, 0.100, 0.107, and 0.109. However, the results obtained by using this method do not indicate any significant improvement. For example, two smoothed trend curves using centred moving averages and Henderson moving averages and the corresponding time series plots for the detrended catch rates are displayed in Figure 3.2. The data set used is the shallow series (depths of 0-20 fathoms) of the season 1998/1999 in Zone C.

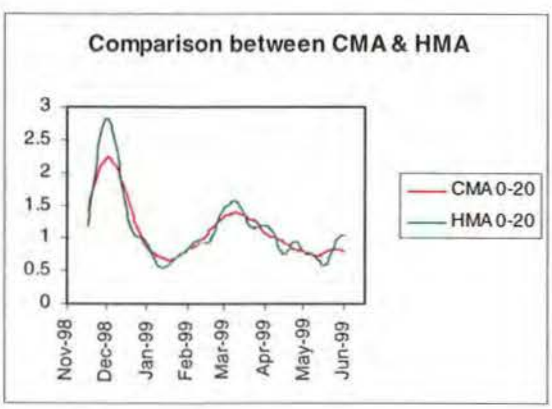


Figure 3.2(a)

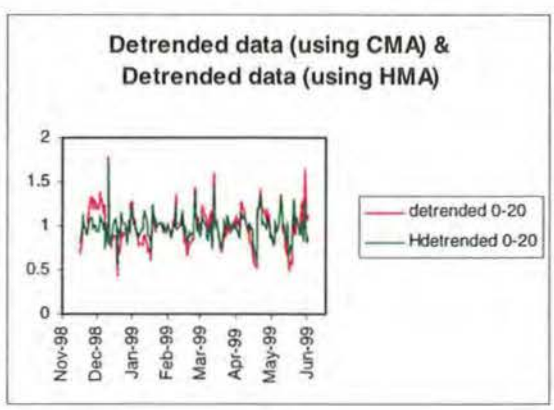


Figure 3.2(b)

Figure 3. 2: Comparison between two smoothed trend curves from centred and Henderson moving averages and the corresponding detrended catch rates obtained for the shallow data set of the fishing season 1998/99 in Zone C.

The smoothed trend curve and the plot of detrended catch rates obtained from centred moving averages are not significantly different from those obtained from Henderson moving averages. In addition, the spectrum of the detrended catch rates achieved by using centred moving averages indicates a cycle of about 30 days while the spectrum of the detrended catch rates obtained by using Henderson moving averages illustrates a cycle of about 60 days in the data. Thus, the spectrum after applying the 31 term Henderson moving average may show that the large cycle length, which is not exactly 30 in the data, may be causing the problem using this approach. Figure 3.3 shows the spectrums of the detrended data obtained by using centred moving averages and Henderson moving averages.

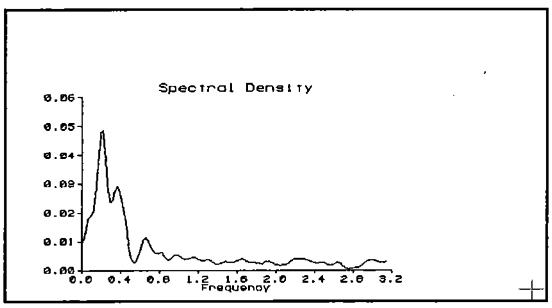


Figure 3.3(a): Spectrum (data obtained by CMA)

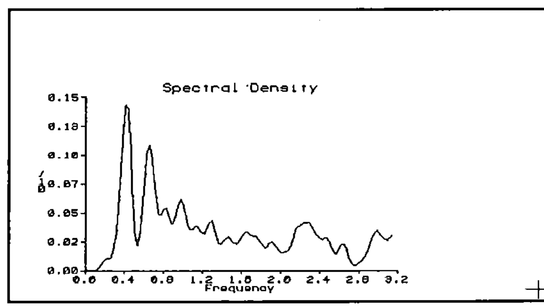


Figure 3.3(b): Spectrum (data obtained by HMA)

Figure 3. 3: Spectrums of the detrended catch rates achieved by using centred moving averages and Henderson moving averages for the shallow data set of the fishing season 1998/99 in Zone C.

3.2 Cross Correlations

Cross correlations represent the degree of linear relationship between two time series at various time lags. Vandaele (1983, p. 269) defined the cross correlations of two time series X_t and Y_t with the same number of observations using the equation below.

$$\rho_{xy}(k) = \frac{\gamma_{xy}(k)}{\sigma_x \sigma_y} \qquad ; k = 0, \pm 1, \pm 2, \ldots \qquad (3.5)$$

where $\gamma_{xy}(k)$; $k = 0, \pm 1, \pm 2, \ldots$ are cross covariances, denoted by

$$\gamma_{xy}(k) = \mathrm{E}[(x_t - \mu_x)(y_{t+k} - \mu_y)] = \mathrm{Cov}(X_t, Y_{t+k}).$$

σ_x and σ_y are the standard deviation values of the series X_t and Y_t.

Cross correlations in this research are used to investigate the relationship between daily data catch rates and three environmental factors (lunar phase, swell, and sea water temperature). Software packages such as Minitab and SPSS can be used to obtain these results. Figure 3.4 given below shows the cross correlations between the catch rates for the 1998/99 season at the depths of 0-20 fathoms in Zone C after removing the trend and the variation of swell during that period obtained by *SPSS*.

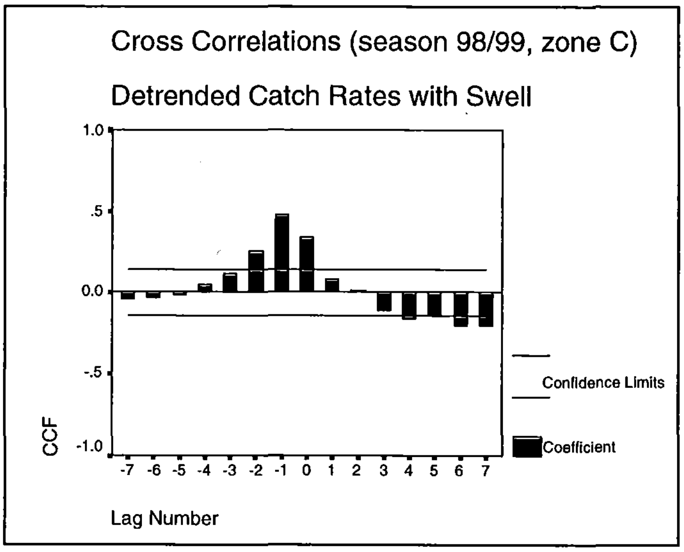


Figure 3. 4: Cross correlations between the catch rates for the 1998/99 fishing season at the depths of 0-20 fathoms (shallow water) in Zone C after removing the trend and the variation of the swell during that period.

The cross correlation function given above illustrates the significant effect of swell on the daily catch rates for shallow water of the 1998/1999 season in Zone C during the day before and the day of the catch. The correlation between swell and the catch rates at the day before and the day of the catch (the higher peaks at lags –1 and 0) is clearer after removing trend and seasonality (called adjusted catch rates in this thesis) with swell in Figure 3.5.

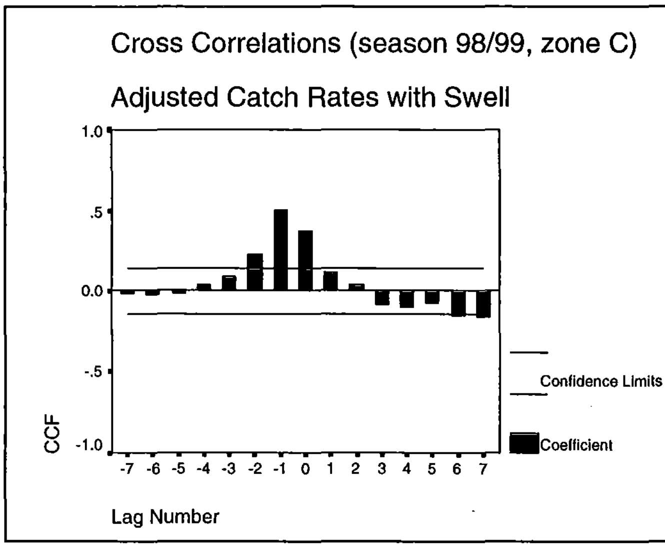


Figure 3. 5: Cross correlations between the catch rates for the 1998/99 fishing season at the depths of 0-20 fathoms (shallow water) in Zone C after removing trend and seasonality and the variation of the swell during that period.

However, Chatfield (1996, p. 139) states a problem in the estimation of cross correlations. For large value of N (pairs of observations), the cross correlation function of two unrelated series may give inaccurate correlation coefficients. The problem occurs since the sequential values from the calculation are autocorrelated to themselves, and the variances in the data correspond to the autocorrelation functions of the two observed series. For the cross correlation function, purely random series or white noise processes after fitting Box-Jenkins models to both estimated time series should be considered to identify if there is correlation between the original time series. Therefore, the cross correlation function between the residuals of the adjusted catch rates and the swell from the fitted models for the shallow data set of the 1998/99 season in Zone C was computed and given in Figure 3.6. The cross correlation function supports the claim that the swell has an effect on the catch rates at the day before the catch because the significant cross correlation appears at lag -1.

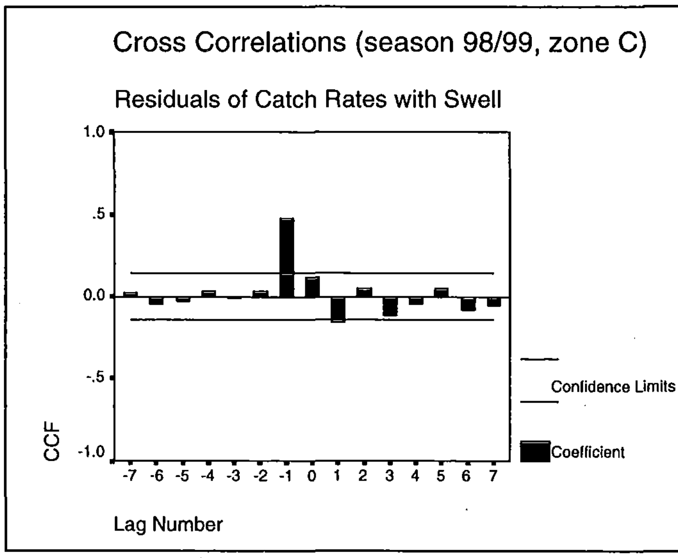


Figure 3. 6: Cross correlations between the residuals of catch rates for the 1998/99 fishing season at the depths of 0-20 fathoms (shallow water) in Zone C and the variation of the swell during that period.

3.3 Classical Decomposition

Classical decomposition is a generally used technique to identify each component in a time series for individual study or to show a clearer image of the data. According to Hanke and Reitsch (1998, p. 303), the four components (trend, cyclical effects, seasonality, and irregular fluctuations) in the observed series can be separated by this method.

A time series X_t can be represented by

$$X_t = f(T_t, C_t, S_t, I_t) \tag{3.6}$$

where T_t is the trend component at time period t.

C_t is the cyclical component at time period t.

S_t is the seasonal component at time period t.

I_t is the irregular (error or random noise) component at time period t.

Two simple models of classical decomposition methods are assumed by equations given as follows.

The additive decomposition model:

$$X_t = T_t + C_t + S_t + I_t \tag{3.7}$$

The multiplicative decomposition model:

$$X_t = T_t \times C_t \times S_t \times I_t \tag{3.8}$$

To obtain each component, moving averages or centred moving averages were first used to remove seasonality and irregular fluctuations. Then the original data were subtracted (for additive series) from, or divided (for multiplicative series) by the trend cyclical component (which results from using moving averages or centred moving averages) to get the seasonal irregular component ($S_t + I_t$ or S_tI_t). The seasonal indices were derived from the seasonal irregular component by finding the medians of the values that were located s positions away from each other (s is the seasonal length). Deseasonalised data were obtained by subtracting or dividing the original data with the seasonal component. In addition, centred moving averages were used as the estimate of the trend curves for the catch rate data in this research.

The classical decomposition command in Minitab allows users to perform the additive or the multiplicative decomposition model on a time series with a linear trend and a seasonal component or with only a seasonal component. The trend in the daily catch rate data has to be removed before using the decomposition in Minitab because there is no evidence of the linear trend in the times series used for this research. Therefore, the option of the multiplicative decomposition model with only a seasonal component was selected after removing the trend. For example, the seasonal component and thirty seasonal indices for the detrended catch rates of the 1998/99 season at shallow water in Zone C can be illustrated in Figure 3.7 as follows.

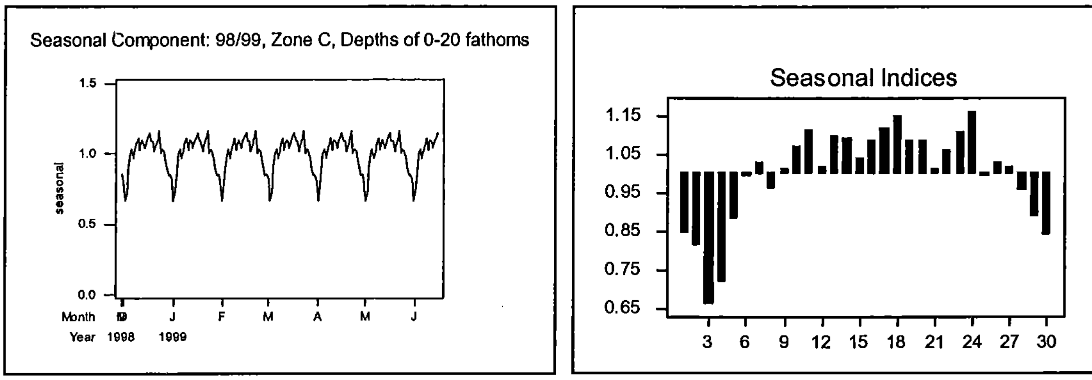


Figure 3. 7: Seasonal component and thirty seasonal indices for the detrended catch rates of the 1998/99 season at shallow water (depths of 0-20 fathoms) in Zone C.

3.4 Holt –Winters Method

The Holt-Winters method or Winters' method is an exponential smoothing technique used for smoothing data when both trend and seasonal variations are presented. It separates a time series into three components which are local level, trend, and seasonal. Newbold and Bos (1990) have given two Holt-Winters models depending on whether the seasonality is additive or multiplicative.

If the seasonality is additive, the equations for local level, trend and additive seasonality are:

$$L_t = \alpha\,(X_t - S_{t-s}) + (1-\alpha)(L_{t-1} + T_{t-1}) \qquad 0<\alpha<1 \qquad (3.9.1)$$

$$T_t = \beta\,(L_t - L_{t-1}) + (1-\beta)\,T_{t-1} \qquad 0<\beta<1 \qquad (3.9.2)$$

$$S_t = \gamma\,(X_t - L_t) + (1-\gamma)\,S_{t-s} \qquad 0<\gamma<1 \qquad (3.9.3)$$

If the seasonality is multiplicative, the equations for level, trend and multiplicative seasonality are:

$$L_t = \alpha\,(X_t / S_{t-s}) + (1-\alpha)(L_{t-1} + T_{t-1}) \qquad 0<\alpha<1 \qquad (3.10.1)$$

$$T_t = \beta\,(L_t - L_{t-1}) + (1-\beta)\,T_{t-1} \qquad 0<\beta<1 \qquad (3.10.2)$$

$$S_t = \gamma\,(X_t / L_t) + (1-\gamma)\,S_{t-s} \qquad 0<\gamma<1 \qquad (3.10.3)$$

where X_t is observations on a time series

L_t, T_t, and S_t are the current level, trend and seasonal index.

α, β, and γ are smoothing parameters of level, trend and seasonal.

s is the seasonal length such as $s = 4$ for quarterly data.

This method can also be applied to cyclic data such as a lunar cycle. Although the lunar cycle seems to appear every 29.5 days, the cyclic length of $s = 30$ can be applied. As a result, the Holt-Winters method is used in this research to validate the use of the classical decomposition to obtain suitable lunar indices for detrended catch rates.

Unlike the classical decomposition method, the Holt-Winters method allows users to estimate the seasonal or cyclic indices by using the original catch rate series which vary with time. For instance, the series of the catch rates for the 1998/99 season at the depths of 0-20 fathoms in Zone C can be separated into level, trend, and seasonal components as shown in Figure 3.8.

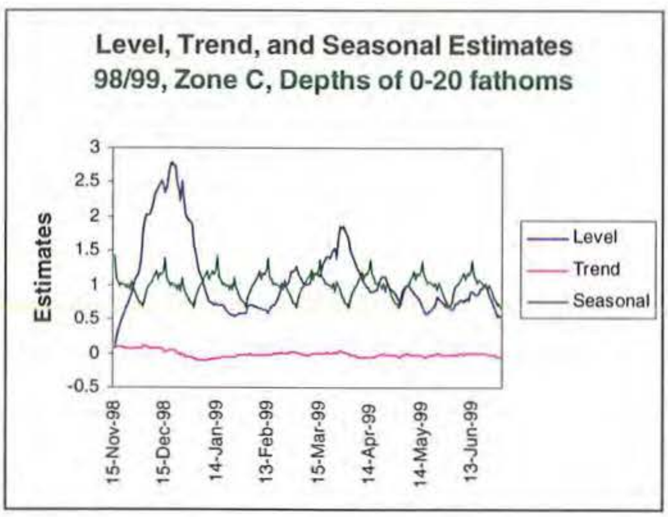


Figure 3. 8: Level, trend, and seasonal estimates for the 1998/99 fishing season at the depths of 0-20 fathoms in Zone C.

3.5 ARIMA Models

According to Box and Jenkins (1976, p. 85), ARIMA models (autoregressive integrated moving average processes) are defined as stationary mixed autoregressive-moving average processes at the *d*th difference. They are used for modelling non-stationary time series behaviour and for creating forecasts. Chatfield (1996, p. 59) denotes an ARIMA process of order (p, d, q) as the equation given below:

$$\phi_p(B)\,(1 - B)^d X_t = \theta_q(B)\, Z_t \tag{3.11}$$

where X_t is a discrete time series, and $B^i X_t = X_{t-i}$ for all i.

Z_t is a purely random process with mean $\mu = 0$ and variance σ^2.

$\phi_p(B) = (1 - \alpha_1 B - \alpha_2 B^2 - \ldots - \alpha_p B^p)$

$\theta_q(B) = (1 + \beta_1 B + \beta_2 B^2 + \ldots + \beta_q B^q)$

$\{\alpha_i \mid i = 1, 2, \ldots, p\}$ and $\{\beta_j \mid j = 1, 2, \ldots, q\}$ are constants.

Cryer (1986) and many other authors provide further detail on autoregressive integrated moving average models (ARIMA) and their use.

ARIMA models are used in this study to examine the behaviour of daily catch rate data. Since the trend in the catch rate data is not linear and it is inappropriate to use differences to remove the trend, only the detrended data were considered for such models. From Figure 3.1, the time series plot of the detrended data for the 1998/99 season in Zone C at the depths of 0-20 fathoms illustrates daily variation in the data. Furthermore, the autocorrelation function (ACF), the partial autocorrelation function (PACF), and spectrum of the detrended data are shown in Figure 3.9. The spectrum illustrates the peak at $\omega = 0.213$ which means that the observed data correspond to a cycle of 29.5 days. However, the ACF and the PACF do not show any significant cyclical pattern because the cycle in the data is not strong enough (the value on the y-axis at the peak is equal to 0.049 which is quite low).

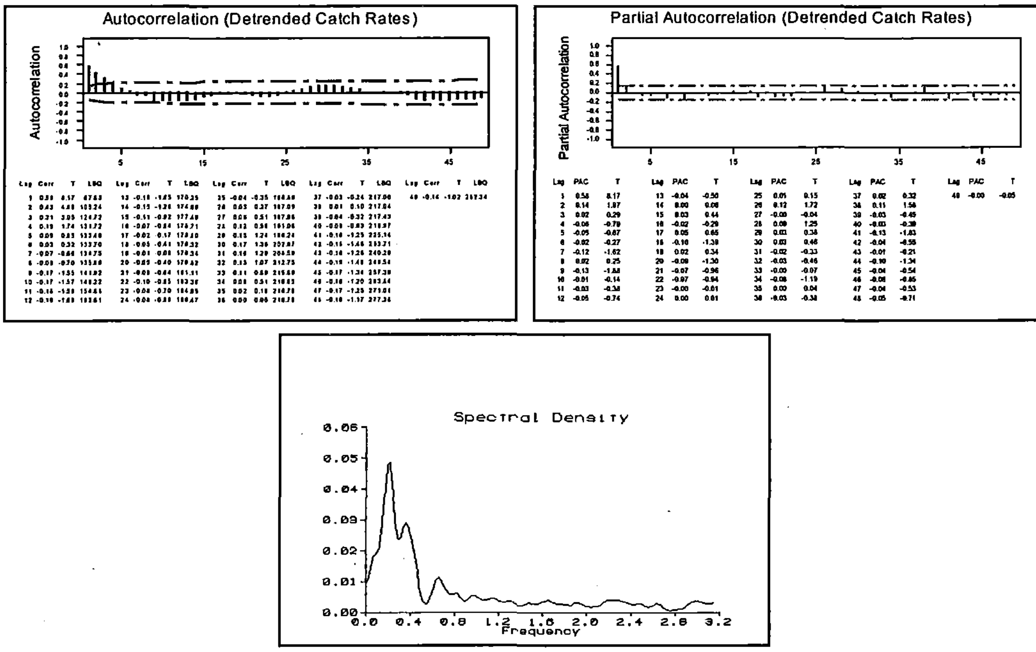


Figure 3. 9: Autocorrelation, Partial Autocorrelation, and Spectrum for the detrended catch rates of the 1998/99 fishing season at the depths of 0-20 fathoms in Zone C.

Based on the ACF and the PACF given above, the model AR (1) or ARIMA (1, 0, 0) seems to be appropriate to fit the data. The Minitab output for this model is given in Table 3.1.

Table 3. 1: *Minitab* output for ARIMA (1, 0, 0) of the detrended data.

ARIMA Model

```
ARIMA model for detrended 0-20

Final Estimates of Parameters
Type          Coef       StDev         T        P
AR   1       0.5884     0.0578      10.18    0.000
Constant    0.41112    0.01205      34.12    0.000
Mean        0.99874    0.02927

Number of observations:  198
Residuals:     SS =  5.63475  (backforecasts excluded)
               MS = 0.02875  DF = 196

Modified Box-Pierce (Ljung-Box) Chi-Square statistic
Lag                12         24         36         48
Chi-Square       13.0       20.1       24.3       35.7
DF                 10         22         34         46
P-Value         0.224      0.574      0.891      0.864
```

The p-value statistics and the examination of residuals indicate that this model is an acceptable fit. The model for the data is defined as follows:

$$(1-0.59B)X_t = Z_t + 0.41 \qquad \text{or} \qquad X_t = 0.59X_{t-1} + Z_t + 0.41$$

This model shows that the detrended catch rate for consecutive days is strongly correlated. Similar models can be obtained for the adjusted catch rates after the lunar cycle has been removed.

3.6 Multiple Regression Models

A multiple regression model presents the combination of two or more independent (predictor or explanatory) variables to estimate a single dependent (response) variable. Relationships between predictor and response variables can be explained from the model.

Suppose that the dependent variable, Y, is the combination of k independent variables, $X_1, X_2, \ldots, X_k$. n observations of Y taken over different lags of time, $Y_t : t = 1, 2, \ldots, n$ can be denoted by:

$$Y_t = \beta_0 + \beta_1 X_{t1} + \beta_2 X_{t2} + \ldots + \beta_k X_{tk} + e_t \qquad : t = 1, 2, \ldots, n \qquad (3.12)$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are fixed parameters or regression coefficients.
$X_{t1}, X_{t2}, \ldots, X_{tk}$ are independent variables of $X_1, X_2, \ldots, X_k$ at lag t.
e_t is an error term (a purely random process) at the tth observation.

The model given above is called as a model of *contemporaneous dependence* by Newbold and Bos (1990, p. 76). The coefficients can be easily estimated using least square approach. However, great care is needed to check that assumptions are met.

The regression model and the ARIMA model are rather similar in character because they both involve equations relating to observations of a time series. Therefore, the regression model can be expanded to incorporate the ARIMA error term. Consider the regression model:

$$Y_t = \beta_1 X_{t1} + \beta_2 X_{t2} + \ldots + \beta_k X_{tk} + e_t \qquad : t = 1, 2, \ldots, n \qquad (3.13)$$

The term e_t in this regression model may be expressed by the ARIMA model satisfying the equation given below.

$$\phi_p(B)\,(1-B)^d\,e_t = \theta_q(B)\,Z_t \tag{3.14}$$

Brockwell and Davis (1996, p. 208) define the model given above by using a matrix notation such as:

$$Y = X\beta + W \tag{3.15}$$

where Y is a matrix consisting of n observations $(Y_1, Y_2, \ldots, Y_n)'$.

X is a matrix consisting of n vectors of k variables $(X_{t1}, X_{t2}, \ldots, X_{tk})'$; $t = 1, 2, \ldots, n$.

β is a matrix of regression coefficients $(\beta_1, \beta_2, \ldots, \beta_k)'$.

W is a matrix consisting of n vectors $(W_1, W_2, \ldots, W_n)'$ where W_t ; $t = 1, 2, \ldots, n$ are observations satisfying the equation

$$W_t = \alpha_1 W_{t-1} + \ldots + \alpha_p W_{t-p} + \ldots + Z_t + \beta_q Z_{t-1} + \ldots + \beta_q Z_{t-q}\ ;\ W_t = (1-B)^d\, e_t.$$

As an example, the multiple regression equation for the required summations of weekly Bump's data with the response variable *Sale* (Y_t), and the predictor variables *Price* (X_{t1}) and *Expense* (X_{t2}) (see Appendix B) stated in Hanke and Reitsch (1998, pp. 247-248) can be calculated by using *Minitab*. The results are given as follows.

Table 3. 2: Multiple regression model for the required summations of Bump's problem.

Regression Analysis

```
The regression equation is
Sale = 16.4 - 8.25 Price + 0.585 Expense

Predictor        Coef        StDev          T        P
Constant       16.406        4.343       3.78    0.007
Price          -8.248        2.196      -3.76    0.007
Expense        0.5851       0.1337       4.38    0.003

S = 1.507        R-Sq = 93.2%      R-Sq(adj) = 91.2%
```

The coefficient of determination R^2 indicates that the proportion of variation (or variability) in sales (in thousands of dollars) that is predicted from the variation (variability) in prices per gallon and expenditures for advertising (in hundreds of dollars) is high (93.2%). Thus, the independent variables X_{t1} and X_{t2} are strongly linearly related to the dependent variable Y_t, and the multiple regression model can be described as the following equation.

$$Y_t = -8.25X_{t1} + 0.585X_{t2} + 16.4$$

3.7 Transfer Function Models

The transfer function model combines the characteristics of an ARIMA model and a multiple regression model. It allows for interdependence of the variables at different time lags. It is a dynamic system which provides a model involving an independent variable or an input series (X_t), a dependent variable or an output series (Y_t), and a disturbance term (N_t). By means of the transfer function structure, the independent variable in current and past time periods has an impact on the dependent variable in the current time period. For a better understanding, the transfer function model is illustrated in Figure 3.10.

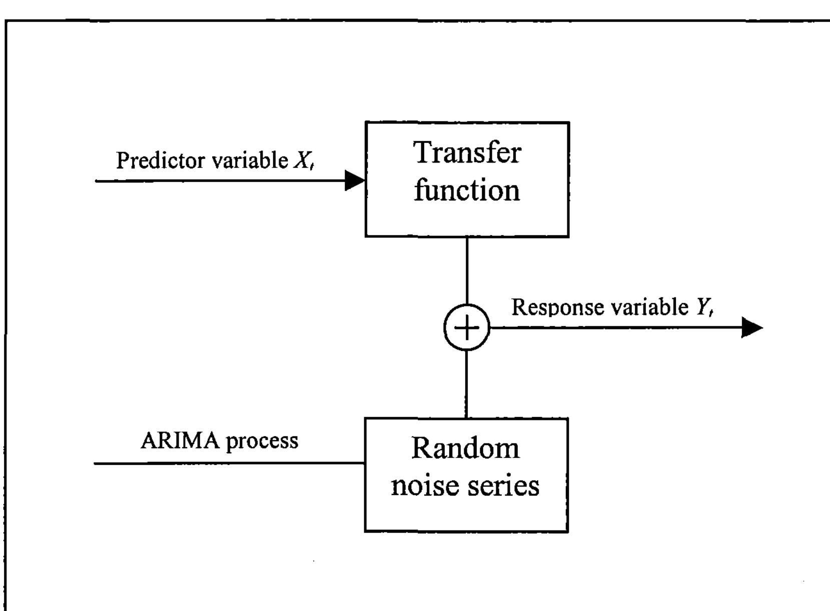


Figure 3. 10: The image of the transfer function model.

Suppose that the input and output series X_t and Y_t are stationary time series, the two general forms of the transfer function model with one input variable at different time lags can be defined as follows:

$$Y_t = \alpha + \nu(B)\, X_t + N_t \tag{3.16}$$

or

$$Y_t = \alpha + \frac{\omega(B)}{\delta(B)} X_{t-b} + N_t \tag{3.17}$$

where α is a fixed parameter.

$\nu(B) = \nu_0 + \nu_1 B + \nu_2 B^2 + \nu_3 B^3 + \ldots$

$\nu_0, \nu_1, \nu_2, \ldots$ are impulse response weights or ν-weights.

$\omega(B) = \omega_0 - \omega_1 B - \omega_2 B^2 - \ldots - \omega_s B^s$

$\delta(B) = 1 - \delta_1 B - \delta_2 B^2 - \ldots - \delta_r B^r$

$X_{t-b} = B^b X_t$

$N_t = \dfrac{\theta(B)}{\phi(B)} a_t$

a_t is a random noise value.

$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots - \theta_q B^q$

$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p$

$\{\nu_i \mid i = 1, 2, \ldots\}$, $\{\omega_j \mid j = 1, 2, \ldots, s\}$, $\{\delta_k \mid k = 1, 2, \ldots, r\}$,

$\{\theta_l \mid l = 1, 2, \ldots, q\}$, and $\{\phi_m \mid m = 1, 2, \ldots, p\}$ are fixed parameters.

r, s, p, q, and b are constants.

The model (3.16) is in a linear form and can be called a linear transfer function model while the model (3.17) is in a rational polynomial form. The input series, X_t, has an effect on the output series, Y_t, but it cannot be reversed (i.e. the response variable Y_t should not affect the predictor variable X_t). Besides, the input series, X_t, here is assumed to be independent from the disturbance term, N_t. Furthermore, additional input variables can also be added to the transfer function model.

Box and Jenkins (1976), Makridakis, Wheelwright, and McGee (1983), and Newbold and Bos (1990) describe transfer function models in more detail.

To illustrate the transfer function modelling approach, the shallow catch rate data of the legal sized lobsters for the season 1998/1999 in Zone C will be considered. The predictor variable or the input series (X_t) here is the swell while the response variable or the output series (Y_t) is the catch rates after removing trend and seasonality.

To build a transfer function model, the input and output series should be identified first in order to provide the determination for the transfer function and the ARIMA model of the disturbance series. ARIMA models of both series were constructed for this purpose. The Minitab outputs are given in the following tables.

Table 3. 3: ARIMA model of the shallow catch rates after removing trend and seasonality for the season 1998/1999 in Zone C.

ARIMA Model: Output Series

```
ARIMA model for Yt

Final Estimates of Parameters
Type          Coef      SE Coef         T        P
AR   1      0.4478       0.0639      7.01    0.000

Number of observations:  196
Residuals:    SS =  4.81931  (backforecasts excluded)
              MS = 0.02471  DF = 195

Modified Box-Pierce (Ljung-Box) Chi-Square statistic
Lag                 12         24         36         48
Chi-Square         7.9       15.4       19.0       28.5
DF                  11         23         35         47
P-Value          0.723      0.878      0.988      0.985
```

Table 3. 4: ARIMA model of the swell for the season 1998/1999 in Zone C.

ARIMA Model: Input Series

```
ARIMA model for Xt

Final Estimates of Parameters
Type          Coef      SE Coef         T        P
AR   1      0.6545       0.0552     11.85    0.000
Constant   0.29452      0.02541     11.59    0.000
Mean       0.85253      0.07354

Number of observations:  196
Residuals:    SS =  24.4970  (backforecasts excluded)
              MS =   0.1263  DF = 194

Modified Box-Pierce (Ljung-Box) Chi-Square statistic
Lag                 12         24         36         48
Chi-Square        14.9       26.3       32.9       47.0
DF                  10         22         34         46
P-Value          0.137      0.239      0.522      0.433
```

It is noted that the constant term for the model in Table 3.3 is insignificant. Consequently, the fitted models for both series are the AR(1) process, and the models obtained can be rewritten as the equations below.

For the output series: $Y_t = 0.448\ Y_{t-1} + Z_t$

For the input series: $X_t = 0.655\ X_{t-1} + Z_t + 0.295$

These results show that there is no need to transform the series before calculating the transfer function model, and there is no seasonality present in the data. However, it is also important to assure that the input and output series are related. Thus, the cross correlation function of both series and that of the residuals for the series after fitting ARIMA models are calculated by using Minitab. The outputs are given in Figure 3.11 and Figure 3.12.

Cross Correlation Function: Y , X

```
CCF - correlates Y(t) and X(t+k)

          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
-12  -0.037                        XX
-11  -0.035                        XX
-10  -0.070                       XXX
 -9  -0.089                       XXX
 -8  -0.031                        XX
 -7  -0.013                         X
 -6  -0.033                        XX
 -5  -0.018                         X
 -4   0.037                         XX
 -3   0.094                         XXX
 -2   0.242                         XXXXXXX
 -1   0.512                         XXXXXXXXXXXXXX
  0   0.379                         XXXXXXXXXX
  1   0.134                         XXXX
  2   0.078                         XXX
  3  -0.063                       XXX
  4  -0.098                       XXX
  5  -0.068                       XXX
  6  -0.138                      XXXX
  7  -0.155                     XXXXX
  8  -0.148                     XXXXX
  9  -0.075                       XXX
 10  -0.014                         X
 11  -0.006                         X
 12  -0.042                        XX
```

Figure 3. 11: Cross correlation function between the adjusted catch rates and the swell for the shallow data set of the season 1998/1999 in Zone C.

Cross Correlation Function: Residuals Y, Residuals X

```
CCF - correlates Res Y(t) and Res X(t+k)

          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
-12   -0.001                          X
-11    0.009                          X
-10   -0.045                         XX
 -9   -0.083                        XXX
 -8    0.029                          XX
 -7    0.020                          X
 -6   -0.046                         XX
 -5   -0.033                         XX
 -4    0.026                          XX
 -3   -0.011                          X
 -2    0.033                          XX
 -1    0.480                          XXXXXXXXXXXXX
  0    0.119                          XXXX
  1   -0.158                      XXXXX
  2    0.048                          XX
  3   -0.118                       XXXX
  4   -0.044                         XX
  5    0.043                          XX
  6   -0.083                        XXX
  7   -0.056                         XX
  8   -0.084                        XXX
  9   -0.001                          X
 10    0.053                          XX
 11    0.038                          XX
 12   -0.022                         XX
```

Figure 3. 12: Cross correlation function between the residuals of the catch rates and those of the swell for the shallow data set of the season 1998/1999 in Zone C.

Both cross correlation functions show that the swell and the catch rates are related. The significant values at lag –1 indicates an effect of the swell on the catch rates at the day before the catch. Therefore, a transfer function model with the output series Y_t (adjusted catch rates) and the input series X_t (swell) can be calculated using the following steps.

The transfer function model was first estimated by using ten impulse response weights and the AR(1) approximation for the disturbance term since the data are nonseasonal. The autocorrelation function for the residuals of the model was computed. The SCA outputs of the model and the ACF are shown as follows.

Table 3. 5: Transfer function model of the shallow data set for the season 1998/1999 in Zone C.

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9899SH	RANDOM	ORIGINAL	NONE
C9899SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1390	.0578	-2.41
2	V0	C9899SW	NUM.	1	0	NONE	.0246	.0291	.85
3	V1	C9899SW	NUM.	1	1	NONE	.2205	.0317	6.95
4	V2	C9899SW	NUM.	1	2	NONE	-.0630	.0318	-1.98
5	V3	C9899SW	NUM.	1	3	NONE	.0087	.0321	.27
6	V4	C9899SW	NUM.	1	4	NONE	.0062	.0323	.19
7	V5	C9899SW	NUM.	1	5	NONE	-.0128	.0321	-.40
8	V6	C9899SW	NUM.	1	6	NONE	-.0092	.0319	-.29
9	V7	C9899SW	NUM.	1	7	NONE	-.0139	.0318	-.44
10	V8	C9899SW	NUM.	1	8	NONE	.0327	.0320	1.02
11	V9	C9899SW	NUM.	1	9	NONE	-.0267	.0321	-.83
12	V10	C9899SW	NUM.	1	10	NONE	-.0105	.0303	-.35
13	PHI1	C9899SH	D-AR	1	1	NONE	.3568	.0683	5.22

```
TOTAL SUM OF SQUARES . . . . . . . .  0.601947E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.333540E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           185
R-SQUARE . . . . . . . . . . . . . .         0.413
RESIDUAL VARIANCE ESTIMATE . . . . .  0.180292E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.134273E+00
```

AUTOCORRELATIONS

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
 1  -0.07                       + XXI    +
 2   0.10                       +    IXXX+
 3   0.05                       +    IX  +
 4   0.14                       +    IXXX+
 5   0.02                       +    IX  +
 6   0.06                       +    IX  +
 7  -0.09                       + XXI    +
 8   0.12                       +    IXXX+
 9  -0.11                       +XXXI    +
10  -0.08                       + XXI    +
11  -0.05                       +  XI    +
12   0.04                       +    IX  +
13  -0.09                       + XXI    +
14  -0.02                       +    I   +
15  -0.02                       +    I   +
16  -0.04                       +  XI    +
17   0.04                       +    IX  +
18  -0.02                       +  XI    +
19   0.14                       +    IXXX+
20   0.03                       +    IX  +
21   0.02                       +    IX  +
22  -0.04                       +  XI    +
23   0.02                       +    IX  +
24  -0.06                       +  XI    +
```

Figure 3. 13: Autocorrelation function for the residuals from the model in Table 3.5.

The ACF of the residuals does not provide any evidence that the model is inappropriate because the residual series corresponds to an independent white noise sequence. Hence, the results from the model can be used for the analysis. From Table 3.5, only the estimate of the ν-weight at lag – 1 (i.e. V1) is significant at the 5% level while the estimate of the ν-weight at lag – 2 or V2 is nearly significant. Thus, two transfer function models given below should be considered.

$$Y_t = \nu_1 X_t + N_t \qquad \text{or} \qquad Y_t = (\nu_1 B + \nu_2 B^2) X_t + N_t$$

Next, the disturbance series has to be identified. The disturbance term was stored from the model in Table 3.5 by using the SCA software package, and the ACF and PACF for this series were calculated. Figure 3.14 illustrates these outcomes.

```
AUTOCORRELATIONS

            -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
              +----+----+----+----+----+----+----+----+----+----+
  1    0.36                         +    IXXX+XXXXX
  2    0.26                         +    IXXX+XX
  3    0.19                         +    IXXX+X
  4    0.21                         +    IXXX+X
  5    0.12                         +    IXXX+
  6    0.09                        +     IXX   +
  7   -0.02                        +     I     +
  8    0.06                        +     IX    +
  9   -0.10                        + XXXI      +
 10   -0.14                        + XXXI      +
 11   -0.09                        +   XXI     +
 12   -0.02                        +     I     +

 PARTIAL AUTOCORRELATIONS

            -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
              +----+----+----+----+----+----+----+----+----+----+
  1    0.36                         +    IXXX+XXXXX
  2    0.15                         +    IXXXX
  3    0.07                         +    IXX +
  4    0.12                         +    IXXX+
  5   -0.01                         +    I   +
  6   -0.01                         +    I   +
  7   -0.10                         + XXI    +
  8    0.06                         +    IX  +
  9   -0.16                         XXXXI    +
 10   -0.10                         + XXI    +
 11    0.03                         +    IX  +
 12    0.06                         +    IXX +
```

Figure 3. 14: ACF and PACF for the disturbance term from the model in Table 3.5.

The ACF dies out in an exponential or sinusoidal fashion, and the PACF cuts off after lag 1. Therefore, the AR(1) model, the MA(1) model, and the ARIMA (1, 0, 1) model were fitted for the disturbance term. Several fitted transfer function models considered for the data are presented in Table 3.6.

Table 3. 6: Various transfer function models of the shallow data set for the season 1998/1999 in Zone C.

	Constant	V1	V2	THETA1	PHI1	R-square	Residual SE
Model 1	– 0.180	0.215		0.539	0.819	42.4	0.133
Model 2	– 0.173	0.208			0.390	39.5	0.136
Model 3	– 0.168	0.203		– 0.300		36.7	0.139
Model 4	– 0.154	0.237	– 0.054	0.538	0.818	43.3	0.132
Model 5	– 0.143	0.227	– 0.055		0.391	40.3	0.135
Model 6	– 0.146	0.224	– 0.048	– 0.297		37.4	0.139

The models with or without the weight V2 show similar results while the models with the disturbance term following the ARIMA (1, 0, 1) model seem to fit the data well (the R^2 values for these models are higher than those with the disturbance following the AR(1) or MA(1) model). Therefore, the model chosen here is the first model, which can be defined as the following equation.

$$Y_t = -0.180 + 0.215 X_{t-1} + \frac{1-0.539B}{1-0.819B} a_t$$

```
AUTOCORRELATIONS

         -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
           +----+----+----+----+----+----+----+----+----+----+
  1   0.01                        +   I    +
  2  -0.03                        +  XI    +
  3  -0.03                        +  XI    +
  4   0.06                        +   IXX  +
  5   0.01                        +   I    +
  6   0.02                        +   IX   +
  7  -0.07                        + XXI    +
  8   0.12                        +   IXXXX+
  9  -0.10                        +XXXI    +
 10  -0.07                        + XXI    +
 11  -0.04                        +  XI    +
 12   0.01                        +   I    +
 13  -0.12                        +XXXI    +
 14  -0.04                        +  XI    +
 15  -0.02                        +  XI    +
 16  -0.03                        +  XI    +
 17   0.02                        +   I    +
 18   0.04                        +   IX   +
 19   0.15                        +   IXXXXX
 20   0.03                        +   IX   +
 21   0.01                        +   I    +
 22  -0.03                        +  XI    +
 23   0.01                        +   I    +
 24  -0.03                        +  XI    +
```

Figure 3. 15: ACF for the residuals of the above transfer function model.

Finally, the diagnostic checks of the model need to be done to investigate the goodness-of-fit of the model. The ACF for the residuals from the above model was estimated and illustrated in Figure 3.15 The SCA output for the ACF shows the pattern of the purely random process in the residual series. As a result, there is no evidence that the model is inappropriate for the data.

Next, since the input series is assumed to be independent from the disturbance of a transfer function model, no significant values should appear in the cross correlation function between the input series and the series a_t. The cross correlation function between the residuals of the transfer function model and the residuals of the ARIMA model for the input series is calculated for this diagnostic check. Figure 3.16 displays the SCA output of this cross correlation function. None of the correlations are significant, so the cross correlation function confirms that the model with the ν-weight at lag – 1 and the disturbance term following the ARIMA (1, 0, 1) model given before seem to fit well to the data for the season 1998/1999 in Zone C.

```
CROSS CORRELATION

             -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
               +----+----+----+----+----+----+----+----+----+----+
-12  -0.05                          +  XI   +
-11  -0.02                          +   I   +
-10   0.01                          +   I   +
 -9  -0.02                          +   I   +
 -8   0.05                          +   IX  +
 -7  -0.02                          +   I   +
 -6  -0.03                          +  XI   +
 -5  -0.02                          +  XI   +
 -4   0.01                          +   I   +
 -3  -0.05                          +  XI   +
 -2  -0.12                          +XXXI   +
 -1   0.05                          +   IX  +
  0   0.09                          +   IXX +
  1  -0.06                          +  XI   +
  2   0.07                          +   IXX +
  3  -0.10                          + XXI   +
  4  -0.03                          +  XI   +
  5   0.01                          +   I   +
  6  -0.05                          +  XI   +
  7  -0.01                          +   I   +
  8  -0.06                          + XXI   +
  9  -0.05                          +  XI   +
 10   0.03                          +   IX  +
 11   0.04                          +   IX  +
 12  -0.01                          +   I   +
```

Figure 3. 16: Cross correlation function between the residuals of the model and the residuals of the input series (the swell for the season 1998/1999 in Zone C).

CHAPTER 4: *ENVIRONMENTAL FACTORS*

In this chapter, the data of catch rates and the impact of the three environmental factors, lunar cycle, swell, and sea water temperature, on these catch rates were investigated. Section 4.1 provides some characteristics of the data sets. The effects of the lunar phase and swell on the daily catch rates are respectively described in sections 4.2 and 4.3. Finally, the examination of the impact of sea water temperature on the catch rates is considered in section 4.4. The research results are numerous due to the large number of the data sets and the variety of the methods used in this thesis. Therefore, only those results that appear to be significant will be included. However, all research outcomes are shown in the attached appendices.

4.1 Exploratory Data Analysis

Throughout this section, the data sets used in the thesis will be explored. Unfortunately, many of the data sets included missing values. A number of the missing values in the daily catch rates are illustrated in Table 4.1. It can be noted that there are more missing values for setose data than for both undersized and legal sized data. In addition, the undersized data have more missing values than the legal sized data. This can be explained by the fact that the legal sized data were consistently recorded by fishers, but the undersized and setose data were poorly recorded because fishers are not required by law to report numbers of undersized and setose lobsters.

After investigation, outliers were identified and removed from the catch rates. Two observations from the legal sized catch rates in deep water (8^{th} and 9^{th} February 1993 in Zone C for the season 1992/1993) and one observation from the undersized catch rates (25^{th} December 1997 in Zone B for the season 1997/1998) were considered erroneous. This is probably due the fact that only a few boats fished on these days (such as Christmas day). The points in these data were significantly higher than other points around them. In addition, they were higher than other observations at the same positions for different seasons. Therefore, the values for these observations were deleted and treated as missing values in further analysis. These points have already been included in a number of missing values in Table 4.1. All of the missing values were calculated and filled in by the STAMP software package. The optimal calculation of these missing values at particular points in time was obtained by adding all the smoothed components together.

Table 4. 1: Numbers of missing values in the daily catch rate data sets considered in this research.

Season And Zone		Lobster Categories			
		Legal size		Undersize	Setose
		Shallow	Deep		
92/93	Zone A	None	None	3	-
	Zone B	-	-	-	-
	Zone C	None	2	7	33
93/94	Zone A	None	None	None	14
	Zone B	1	1	6	-
	Zone C	6	-	10	-
94/95	Zone A	1	-	2	-
	Zone B	2	2	5	-
	Zone C	-	-	-	-
95/96	Zone A	None	None	None	-
	Zone B	None	None	None	-
	Zone C	None	None	6	35
96/97	Zone A	None	None	None	-
	Zone B	None	None	None	-
	Zone C	None	None	-	24
97/98	Zone A	None	None	None	-
	Zone B	1	1	3	-
	Zone C	1	1	-	-
98/99	Zone A	None	None	3	-
	Zone B	None	None	-	-
	Zone C	None	None	-	-

The plots of the daily catch rate data in Zone A, Zone B, and Zone C for each fishing season are provided in Appendix C. The fishing season for Zone A starts in March in place of November as that for Zone B and Zone C. Moreover, catch rates in Zone A are clearly different from those in the other two zones, which are rather similar to each other. The graphs for legal sized lobsters caught in Zone A illustrate a pattern where the catch rates were optimal at the beginning of the season and continuously declined until the end of the season. Likewise, the graphs for undersized lobsters in Zone A show the same pattern as those for legal sized lobsters, however, more varied. Plots for the catch rates in Zone B and Zone C have fairly similar characteristics where catch rates in both zones increase at the beginning of the season and decline to a minimum point towards the end of January. They then start increasing again in the beginning of February and remain relatively constant for the remainder of the season. This pattern is related to the periods of whites and reds as mentioned in section 1.1. Figure 4.1 shows the time series plots of the legal sized catch rates in shallow water for the fishing season 1998/1999 in the three different zones. These graphs confirm the patterns of the catch rate series mentions before.

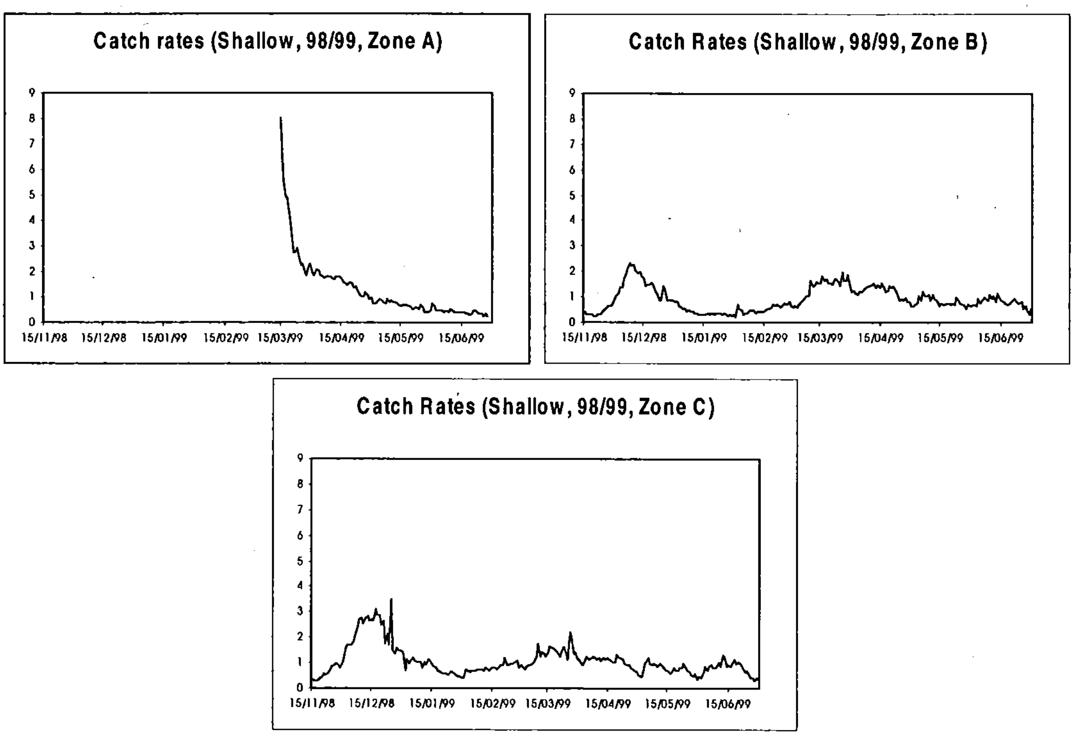


Figure 4. 1: Time series plots of legal sized catch rates in shallow water for the fishing season 1998/1999 in Zone A, Zone B, and Zone C.

The prediction of these catch rate characteristics is quite important for fishers because it can tell them when the best fishing will take place. In addition, it is also important to understand the factors affecting the catch rates for fisheries scientists who use catch rates as indicators of abundance. One way to estimate these patterns is indicating the environmental factors related to the catch rates. Therefore, the effects of environmental factors such as lunar cycle, swell, and sea water temperature on the catch rates will be examined in the next sections.

4.2 Lunar Phase

Roberts (2000) in her thesis identified the impact of the lunar phase on the catch rates of the western rock lobster. The results in this section validate and extend from the work undertaken by Roberts. Section 4.2.1 shows the results of the cyclical pattern after removing the trend while section 4.2.2 outlines the cyclic indices derived from two methods, classical decomposition and Holt-Winters, compared with four moon phases.

4.2.1 Detrended Data Compared with Lunar Phase

In Roberts' study, both a 30 point moving average and a 6^{th} degree polynomial were used to estimate and remove the trend, and little difference was observed in the outcomes of both methods. Therefore, only 30-day centred moving averages were used to remove the trend from the series in this research. Weighted moving averages were considered to suppress the cycle in the adjusted time series but no significant improvement was observed. After calculating detrended data of the catch rates by using equation (3.3), a cyclical pattern appeared in the series. To investigate the cyclical behaviour, the detrended series of all catch rates considered in this research were plotted against the four moon phases for each fishing season in each zone (See Appendix D). These detrended series start 15 days later and end 15 days before their original catch rate series because 30 observations are lost at either end of each series due to the methods used. The brown lines in each plot from Appendix D represent the four moon periods (actual date of the full moon, the last quarter, the new moon, and the first quarter ± three days[5]). The lowest line stands for the period when the full moon occurs whilst the next three lines correspondingly represent the periods of the last quarter phase, the new moon phase, and the first quarter phase. Figure 4.2 illustrates the graphs of the catch rates in shallow water after removing the trend for the fishing season 1998/1999 in the three different zones.

[5] More detail is available in Roberts (2000, p. 43) or Courtney, Die, and McGilvray (1996).

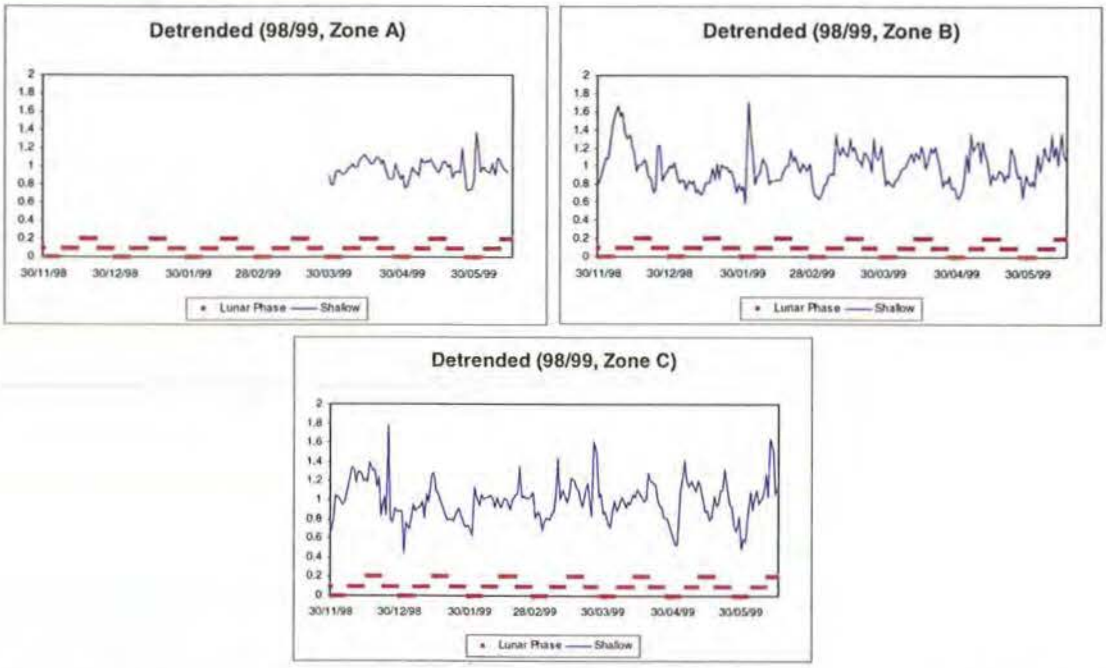


Figure 4. 2: Time series plots of the detrended catch rates for legal sized lobsters in shallow water during the season 1998/1999 in the three different zones against the four moon phases.

From a visual viewpoint, the plots of detrended data in Zone A do not show any clear cyclical patterns. Although minima of the data for legal sized and undersized lobsters seemed to appear when the full moon occurred, the data values did not change much during the examined period, and the cyclical pattern is not strong. The reason is probably because the length of the data used for the investigation for this zone is too short (only three months of data after removing the trend). Unlike the detrended series in Zone A, plots for the data in Zone B and Zone C illustrate clearer and stronger cycles with minimum values at the stages of the full moon phase. However, it was observed that the cyclical pattern is unclear especially from the beginning of the season to the end of February for every category and for the end of the season for legal sized lobsters in deep water and for setose lobsters (available only for some fishing seasons in Zone C). As a result, the cycle is more pronounced in the period of reds than in that of migratory whites. The cyclical pattern in the detrended series of the legal sized lobsters in shallow water seems to be the strongest pattern compared with those of the legal sized lobsters in deep water and the other categories. Figure 4.3 shows examples of the cycle appearing in the detrended catch rates for legal sized, undersized, and setose lobsters in Zone C during the fishing season 1995/1996.

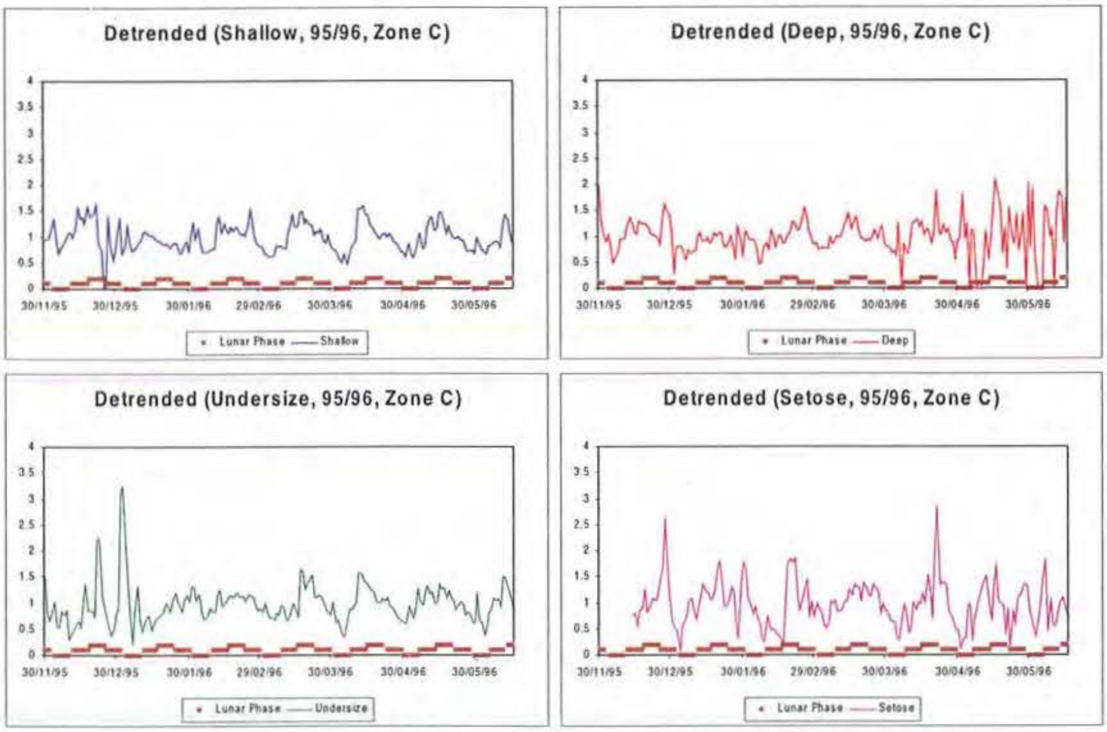


Figure 4. 3: Time series plots of the detrended catch rates for legal sized (in shallow and deep water), undersized, and setose lobsters during the season 1995/1996 in Zone C against the four moon phases (the detrended data for the setose lobsters at the start of the season are not obtainable because of missing data).

It is noted that a peak in the middle of February of the series for legal sized lobsters in deep water caught in Zone B concurs with the opening of the Big Bank fishing area, north of Abrolhos Island, which is a part of Zone B. Figure 4.4 illustrates a peak of the data for the fishing season 1998/1999 in Zone B during the opening time of the Big Bank fishing region.

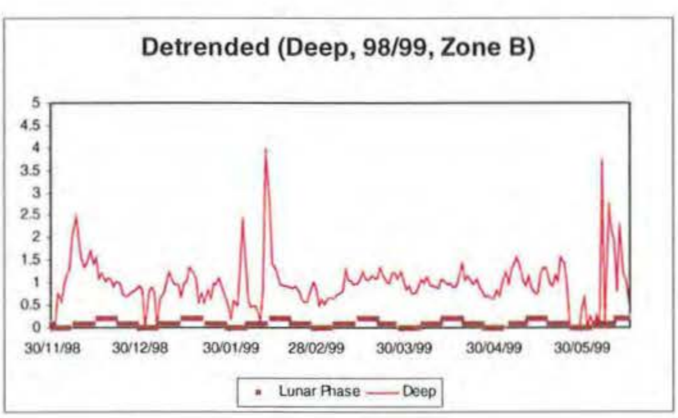


Figure 4. 4: Graph of the detrended catch rates for legal sized lobsters in deep water during the fishing season 1998/1999 in Zone B against the four moon phases.

4.2.2 Cyclic Indices Compared with Lunar Phase

In this study, two methods, classical decomposition and Holt-Winters, were used to estimate the cyclic indices of the daily catch rates. These values are measured in the form of medians. The two methods for estimating cyclic indices have already been explained in sections 3.3 and 3.4 in chapter 3. Median values were used to obtain a set of 30 cyclic indices. Unlike cyclic indices calculated by the classical decomposition method, each set of 30 indices derived from the Holt-Winters method varies slightly over the length of the season. However, 30 median cyclic indices were chosen from those calculated by the Holt-Winters method for every data set used in this research in order to compare the results from both techniques and to confirm the accuracy of the outcomes from the decomposition method. The plots of 30 cyclic indices estimated by both methods were then compared with the four moon phases for every season and every zone. The graphs for this study are given in Appendix E. The graphs indicate a 30-day cycle with minima during the full moon period. Figure 4.5 displays this cyclical pattern for legal sized lobsters caught from Zone B and Zone C in shallow water.

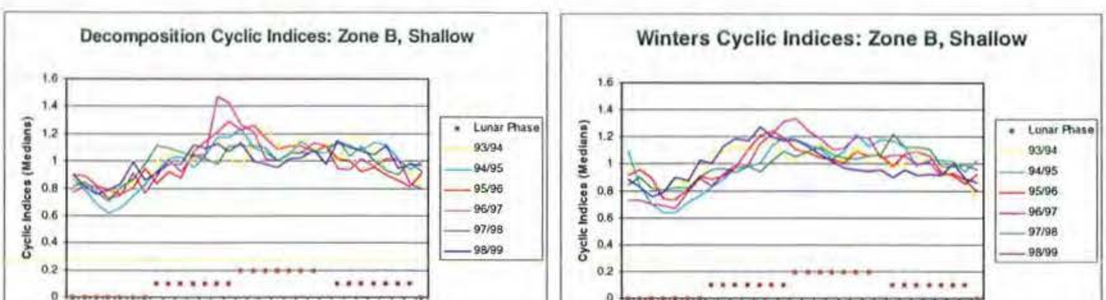


Figure 4. 5: Time series plots of 30 cyclic indices derived from the decomposition and Holt-Winters methods compared with the lunar cycle for legal sized lobsters caught in Zone B and C in shallow water of every fishing season considered for these two zones.

In general, the cyclical pattern has its minimum during the full moon period with the approximate index of 0.7 for catch rates of legal sized lobsters in both shallow and deep water and for catch rates of undersized lobsters. The cycle in catch rates of legal sized lobsters in shallow water seems to show the strongest pattern. The same pattern does not appear for some of the fishing seasons of undersized lobsters in Zone A. For setose lobsters, the pattern occurs in the catch rates of Zone C for every considered data set, but it does not appear in the data set for the season 1993/1994 in Zone A, which is the only data set of setose lobsters used for Zone A in this research.

Next, cyclic indices for the catch rates were calculated for two different periods, the early season or the period of whites and the late season or the period of reds. The decomposition and the Holt-Winters methods were used in order to compare the results from these two periods. Therefore, cyclic indices of the catch rates in Zone B and Zone C for each season are separately investigated while those in Zone A are not examined due to its shorter fishing period. Time series plots of 30 cyclic indices compared with the four moon phases for both periods of whites and reds for every available data set in Zone B and C are shown in Appendix E. The time series plot of 30 cyclic indices for legal sized lobsters caught in Zone B in deep water during the period of whites in the season 1996/1997 was unavailable because the catch rates were inappropriate to use the Holt-Winters method. Likewise, the plots of the indices for setose lobsters during the period of whites in Zone C estimated by the decomposition method were not obtainable because the lengths of the data were too short for the calculation.

From the graphs given in Appendix E, there is no evidence of a clear cyclical pattern for the whites stage although some of the plots have minima during the full moon period. On the other hand, the graphs of catch rates during the reds stage in both Zone B and Zone C illustrate strong cyclical patterns that have minima during the full moon ± three days. Unlike the catch rate indices for the whites period, it is clear that the catch rate indices for the reds period are similar to those for the period over the full fishing season. This can be explained by the fact that the period of reds, 1st February to the 30th June, is twice as long as that of whites, 15th November to the 31st January, in every fishing season. An example of 30 cyclic indices for catch rates of whites and reds is given in Figure 4.6. The indices of legal sized lobsters in shallow water and undersized lobsters in Zone B during the periods of whites and reds are shown in this figure.

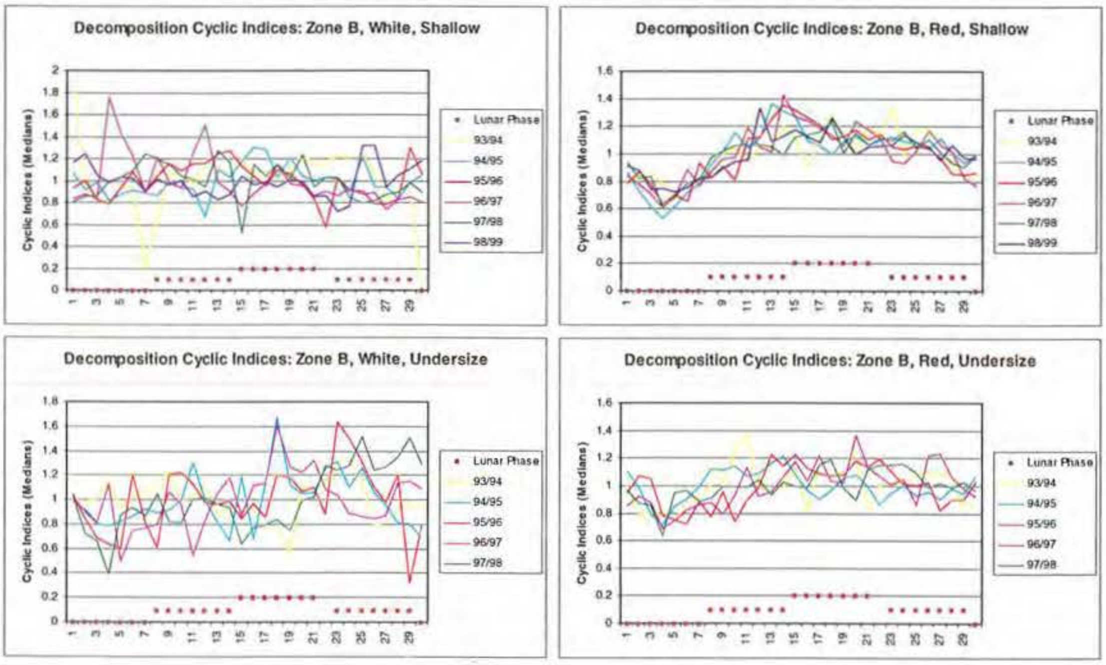
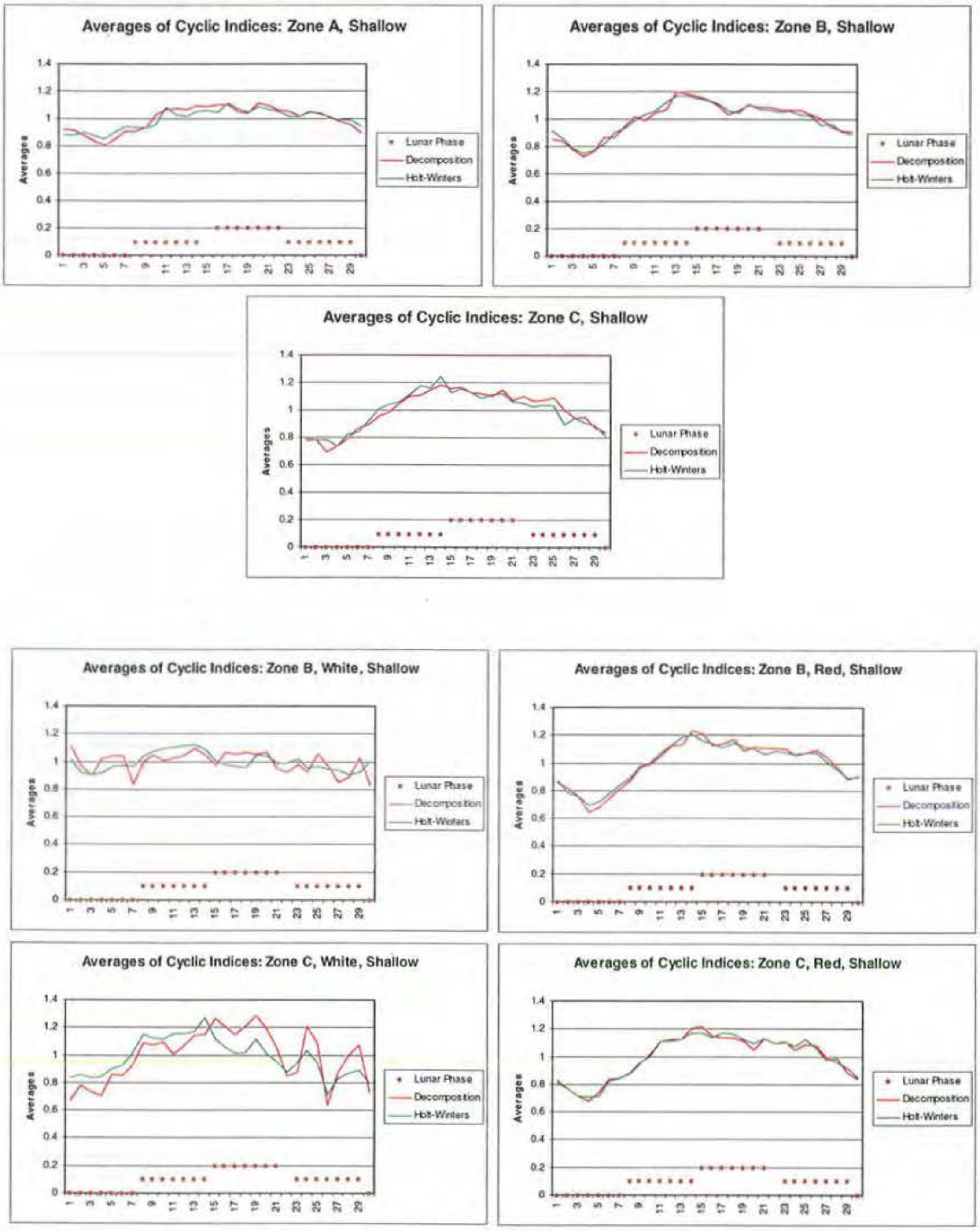


Figure 4. 6: Time series plots of 30 cyclic indices derived from the decomposition method comparing the lunar cycle for legal sized lobsters in shallow water and undersized lobsters in Zone B of every fishing season available for this zone.

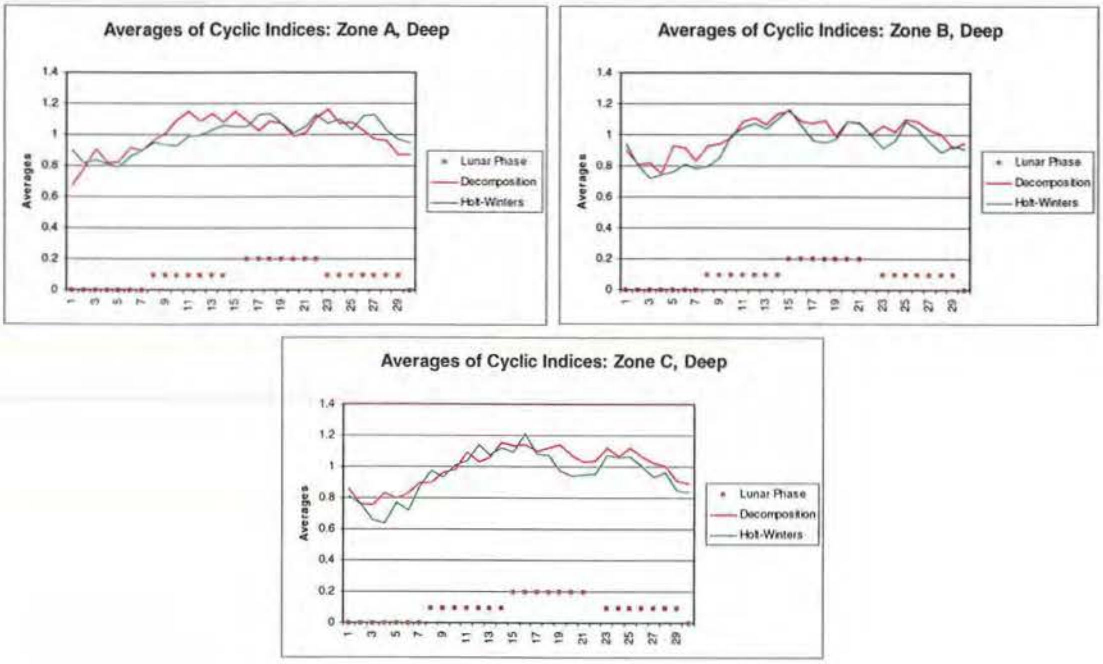
To investigate the general behaviour of the cyclic indices for the catch rates of the western rock lobster over all years, the mean values of the 30 indices for each category of the rock lobsters and each zone including means of the indices for the catch rates during the periods of whites and reds were computed. The graphs of these values from both the decomposition and Holt-Winters methods are shown in Figure 4.7, Figure 4.8, Figure 4.9, and Figure 4.10 as follows.



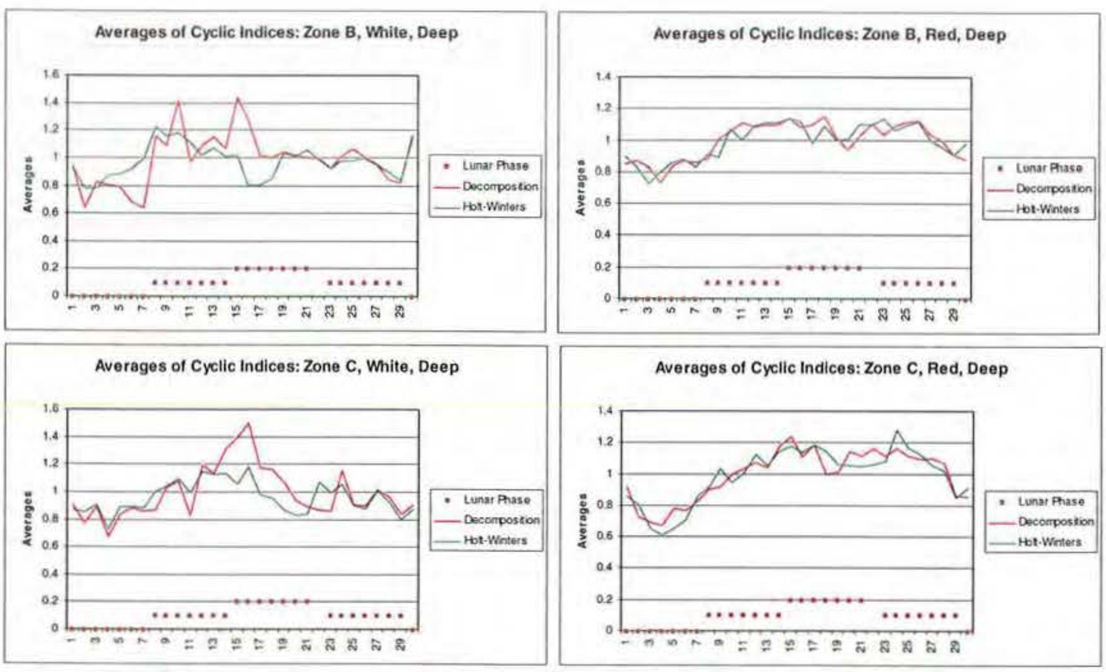
(b) Period of whites

(c) Period of reds

Figure 4. 7: Averages of 30 cyclic indices for catch rates of legal sized lobsters in shallow water in each zone including averages of the indices for the catch rates during the periods of whites and reds in Zone B and Zone C.

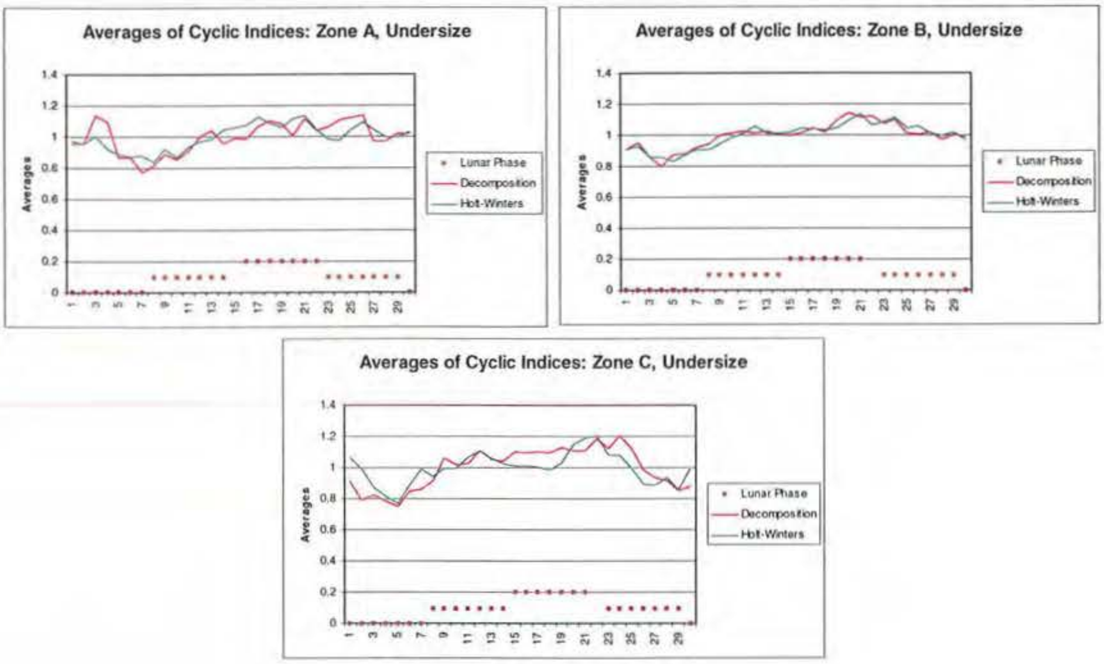


(a) Whole period of the fishing season

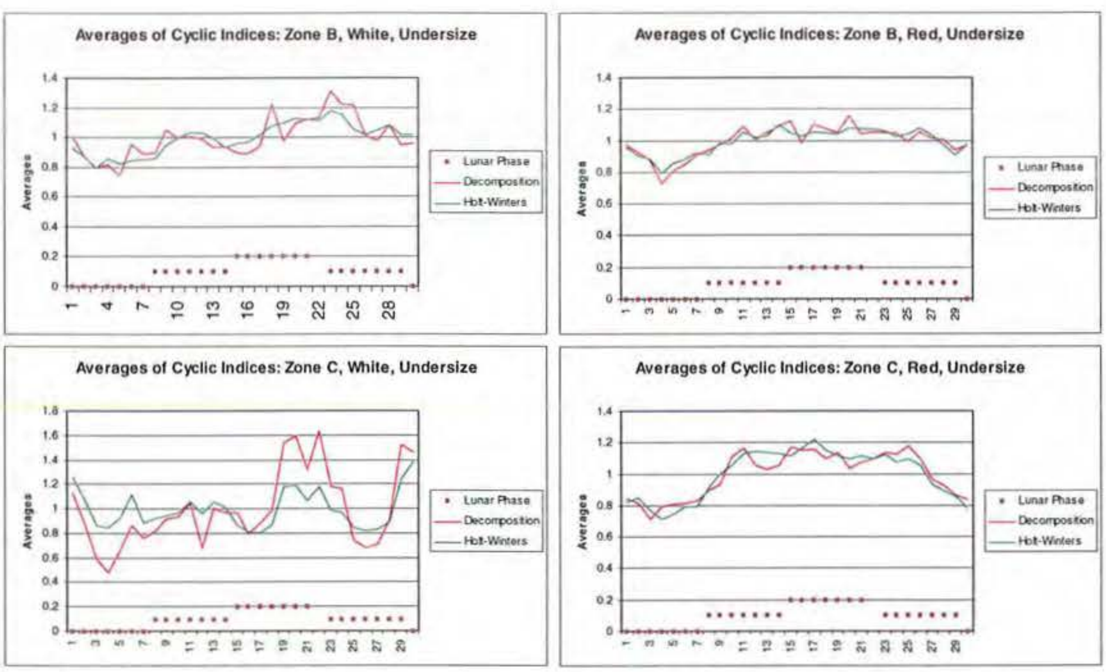


(b) Period of whites (c) Period of reds

Figure 4. 8: Averages of 30 cyclic indices for catch rates of legal sized lobsters in deep water in each zone including averages of the indices for the catch rates during the periods of whites and reds in Zone B and Zone C.



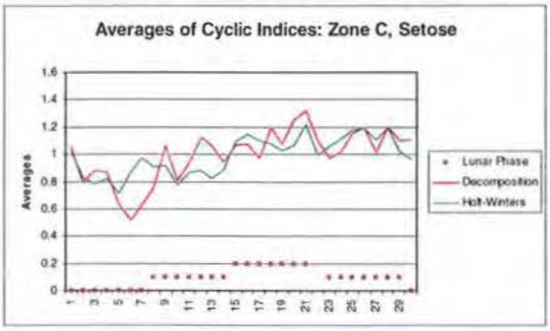
(a) Whole period of the fishing season



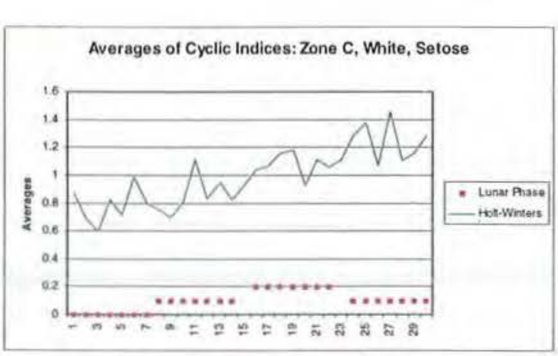
(b) Period of whites

(c) Period of reds

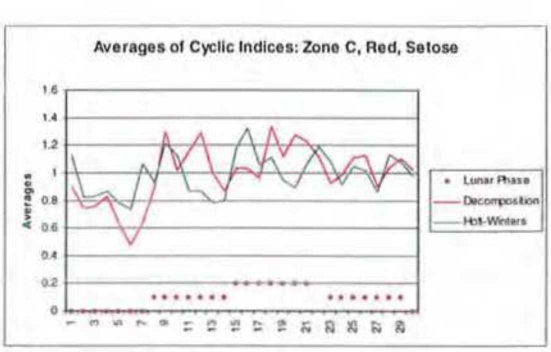
Figure 4. 9: Averages of 30 cyclic indices for catch rates of undersized lobsters in each zone including averages of the indices for the catch rates during the periods of whites and reds in Zone B and Zone C.



(a) Whole period of the fishing season



(b) Period of whites



(c) Period of reds

Figure 4. 10: Averages of 30 cyclic indices for catch rates of setose lobsters including averages of the indices for the catch rates during the periods of whites and reds in Zone C.

The cycle in general has low values during the full moon period, increasing values during the last quarter period, high values during the new moon period, and decreasing values during the first quarter period. In addition, Figure 4.7 and Figure 4.8 illustrate that most averages of the indices for the whole period over the season of legal sized lobsters in both shallow and deep water especially in Zone B and Zone C reach their maximum values at the end of the last quarter period or at the beginning of the new moon period. The average values of both decomposition and Holt-Winters methods are quite similar for the 30 indices of legal sized lobsters in shallow water and slightly different for those in deep water. The averages of the indices for the period of reds have the same pattern as those for the whole season while those for the period of whites are more fluctuated but still maintain the general configuration.

The averages for undersized lobsters in Figure 4.9 show the maxima falling towards the late period of the new moon phase or the early period of the first quarter phase. Thus, the catch rate of undersized lobsters is significantly higher than the average trend during that time. As the averages for legal sized lobsters, the values for undersized lobsters during the whites phase are more varied than those during the other two periods. However, the main configurations of these average values for all periods are similar. The pattern where the minimum occurs during the full moon period also appears for setose lobsters in Zone C as shown in Figure 4.10. Nevertheless, no exact conclusion can be drawn since only data sets from three fishing seasons were used to obtain these plots.

To summarise the above results, means and standard deviations of the averages for each moon phase in each data set were estimated. The values were separated into different categories, zones, and fishing periods depending on the availability of the data sets. The calculation was carried out for 30 cyclic indices using both decomposition and Holt-Winters methods. These means and standard deviations of the average values are shown in Table 4.2 as follows.

Table 4. 2: Means and standard deviations of the averages for each moon phase of all examined series.

Category, Zone, & Period		Method	Full Moon		Last Quarter		New Moon		First Quarter	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shallow	Zone A	Decomposition	0.8738	0.0449	1.0278	0.0728	1.0835	0.0260	1.0177	0.0359
		Holt-Winters	0.8927	0.0276	1.0029	0.0596	1.0700	0.0232	1.0181	0.0204
	Zone B	Decomposition	0.8172	0.0564	1.0668	0.0949	1.0989	0.0407	1.0155	0.0618
		Holt-Winters	0.8301	0.0648	1.0719	0.0905	1.0967	0.0371	1.0035	0.0580
	Zone B White	Decomposition	0.9919	0.0938	1.0433	0.0307	1.0235	0.0611	0.9615	0.0721
		Holt-Winters	0.9556	0.0388	1.0953	0.0265	0.9999	0.0321	0.9527	0.0371
	Zone B Red	Decomposition	0.7637	0.0768	1.0585	0.1185	1.1363	0.0391	1.0356	0.0790
		Holt-Winters	0.7815	0.0634	1.0728	0.1139	1.1180	0.0292	1.0226	0.0730
	Zone C	Decomposition	0.7952	0.0698	1.0786	0.0843	1.1283	0.0338	1.0019	0.0824
		Holt-Winters	0.8129	0.0604	1.1187	0.0839	1.1085	0.0366	0.9637	0.0691
	Zone C White	Decomposition	0.7950	0.0962	1.0937	0.0503	1.1568	0.1408	0.9696	0.1885
		Holt-Winters	0.8925	0.0677	1.1683	0.0515	1.0244	0.0812	0.8951	0.1022
	Zone C Red	Decomposition	0.7758	0.0651	1.0604	0.1145	1.1334	0.0493	1.0321	0.0728
		Holt-Winters	0.7707	0.0574	1.0548	0.1055	1.1408	0.0306	1.0349	0.0847
Deep	Zone A	Decomposition	0.8335	0.0861	1.0785	0.0663	1.0714	0.0538	1.0238	0.0953
		Holt-Winters	0.8472	0.0438	0.9864	0.0500	1.0818	0.0455	1.0675	0.0583
	Zone B	Decomposition	0.8520	0.0663	1.0383	0.0832	1.0722	0.0505	1.0341	0.0606
		Holt-Winters	0.7979	0.0735	0.9895	0.1165	1.0360	0.0757	0.9701	0.0718
	Zone B White	Decomposition	0.7673	0.1114	1.1384	0.1388	1.1033	0.1674	0.9523	0.0897
		Holt-Winters	0.8875	0.0773	1.1174	0.0835	0.9503	0.1045	0.9413	0.0523
	Zone B Red	Decomposition	0.8398	0.0480	1.0503	0.0791	1.0715	0.0699	1.0457	0.0776
		Holt-Winters	0.8352	0.0549	1.0294	0.0945	1.0687	0.0621	1.0418	0.0887
	Zone C	Decomposition	0.8229	0.0512	1.0296	0.0845	1.1004	0.0451	1.0472	0.0768
		Holt-Winters	0.7508	0.0834	1.0458	0.0752	1.0386	0.0952	0.9950	0.0834
	Zone C White	Decomposition	0.8367	0.0836	1.0692	0.1734	1.1322	0.2320	0.9551	0.1090
		Holt-Winters	0.8656	0.0594	1.0833	0.0648	0.9774	0.1254	0.9421	0.0885
	Zone C Red	Decomposition	0.7737	0.0844	1.0251	0.0951	1.1252	0.0807	1.0779	0.0967
		Holt-Winters	0.7368	0.1027	1.0365	0.0831	1.1129	0.0575	1.0858	0.1324
Undersize	Zone A	Decomposition	0.9540	0.1308	0.9263	0.0794	1.0513	0.0510	1.0576	0.0694
		Holt-Winters	0.9278	0.0491	0.9398	0.0699	1.0896	0.0332	1.0236	0.0422
	Zone B	Decomposition	0.8860	0.0487	1.0058	0.0274	1.0705	0.0555	1.0289	0.0469
		Holt-Winters	0.8847	0.0330	0.9909	0.0518	1.0629	0.0383	1.0505	0.0427
	Zone B White	Decomposition	0.8719	0.0914	0.9773	0.0525	1.0367	0.1236	1.1140	0.1411
		Holt-Winters	0.8581	0.0434	0.9752	0.0637	1.0643	0.0700	1.0834	0.0644
	Zone B Red	Decomposition	0.8717	0.0825	1.0260	0.0569	1.0771	0.0542	1.0180	0.0418
		Holt-Winters	0.8907	0.0522	1.0160	0.0621	1.0609	0.0187	1.0235	0.0571
	Zone C	Decomposition	0.8257	0.0526	1.0339	0.0588	1.1179	0.0310	1.0220	0.1291
		Holt-Winters	0.9159	0.1063	1.0299	0.0549	1.0748	0.0918	0.9635	0.0918
	Zone C White	Decomposition	0.7741	0.2150	0.9154	0.1246	1.2221	0.3451	0.9903	0.3151
		Holt-Winters	1.0012	0.1561	0.9938	0.0523	1.0000	0.1738	0.9456	0.1491
	Zone C Red	Decomposition	0.8059	0.0439	1.0376	0.0948	1.1186	0.0465	1.0442	0.1208
		Holt-Winters	0.7891	0.0453	1.0769	0.0882	1.1376	0.0405	1.0081	0.1087
Setose	Zone C	Decomposition	0.7719	0.1829	0.9594	0.1349	1.1362	0.1128	1.0976	0.0918
		Holt-Winters	0.8630	0.1062	0.8698	0.0517	1.0931	0.0680	1.1253	0.0675
	Zone C White	Holt-Winters	0.7865	0.1278	0.8584	0.1390	1.0849	0.0801	1.2523	0.1434
	Zone C Red	Decomposition	0.7178	0.1397	1.0795	0.1773	1.1447	0.1306	1.0328	0.0921
		Holt-Winters	0.8953	0.1462	0.9452	0.1650	1.0996	0.1394	1.0247	0.0977

4.3 Swell

In this thesis, the impact of swell on the catch rates for all data sets, including the data series after separating into two parts, whites and reds, was examined by first using cross correlations. The trend was removed before using cross correlations to find the relationship between the catch rates and swell, as the swell has no impact on the underlying trend. Then, the influence of the swell on the catch rates after removing both trend and cyclic components (adjusted catch rates) was investigated. The results demonstrate that the cross correlations between the detrended data and the swell show some significant values at some lags. However, the cross correlations of the adjusted catch rates with the swell provide a clearer indication of the relationship for all investigated data sets. Moreover, the significant lags in cross correlations of both detrended and adjusted data with the swell for the data series are similar. Therefore, in this section, only the cross correlations of the adjusted catch rates with the swell will be discussed due to the large number of computations.

Appendix F illustrates the cross correlations between the adjusted data and the swell for all examined series. The relationships between the catch rates in each zone and each category for the whole period during the fishing season of western rock lobsters with swell have been summarised as follows:

Zone A: Legal sized lobsters

In shallow water, the swell does not seem to have any effects on the catch rates. There was no evidence of any strong significant values at any lags in the cross correlations of the adjusted catch rates of this category with the swell.

In deep water, most of the cross correlation functions (those for the seasons 1992/1993, 1993/1994, 1995/1996, and 1996/1997) show the significant values at lag –1 with the correlations varying from 28% to 47.4%. Only few cross correlation functions show the significant values at lag 0 or lag –2. Thus, the swell appears to have a significant effect on the catch rates at the day before the catch.

Zone A: Undersized lobsters

There was no consistent result for this lobster category. The cross correlations have the significant values at different lag numbers for different fishing seasons. However, the interesting outcome is that almost all of the significant values occurring in the cross correlation functions were negative.

Zone A: Setose lobsters

The cross correlations for this category were calculated only from the season 1993/1994 because of missing values in the catch rate data. However, the cross correlation functions of the adjusted catch rates with swell for the fishing season do not show any significant impact for swell on catch rates.

Zone B: Legal sized lobsters

In shallow water, the swell appears to have a significant effect on the catch rates the day before and possibly two days before the catch. All graphs of cross correlations for the data show a significant value at lag –1 varying from 15.6% to 40.9%. Some of the cross correlations also have significant values at lag –2. In addition, few of them are significant at lag 0.

In deep water, half of the cross correlation functions considered (i.e. those for the seasons 1993/1994, 1995/1996, and 1998/1999) have significant values at lag –1 while at least one of these correlation functions has a significant value at lag –2 or lag 0. The range of cross correlation values for lag –1 was located between 19.9% and 31.4%. Thus, the swell possibly has a significant effect on the catch rates the day before the catch. Moreover, the impact of the swell on catch rates in shallow water is stronger than that in deep water since the significant values of the cross correlations for the legal sized lobsters in shallow water are higher than those in deep water.

Zone B: Undersized lobsters

Although some of the cross correlations in different fishing seasons are significant at lag 0 with the negative values, the cross correlation functions for this lobster category in Zone B did not illustrate any clear evidence for the impact of the swell on the undersized catch rates.

Zone C: Legal sized lobsters

For the category, in shallow water, the cross correlations of all examined fishing seasons have the significant values at lag –1 and lag 0 (the correlations range from 25.8% to 51.8% and from 16.4% to 38.1% respectively). However, the correlation values of lag –1 are higher than those of lag 0 for every season. Besides, almost all of the correlations at lag –2 are significant. Therefore, the swell has the influence on the catch rates for the previous two days and for the day of the catch.

In deep water, the effect of swell on catch rates is not as clear compared with that of shallow water. However, it seems that swell has an impact on the catch rates the day before the catch because most of the examined correlation functions, which are those for the seasons 1992/1993, 1996/1997, 1997/1998, and 1998/1999, show the significant values at lag –1. The range of the correlation values is from 15.3% to 45.5%.

Zone C: Undersized lobsters

Only the results from the seasons 1992/1993, 1993/1994, and 1995/1996 were available for this category due to missing data for other seasons. None of the cross correlations calculated for the catch rate data have strong significant values in any lags. Therefore, there is no evidence of any impact for swell on the catch rates of undersized lobsters in Zone C.

Zone C: Setose lobsters

Only the data for three fishing seasons (1992/1993, 1995/1996, and 1996/1997) were calculated for this category because of the same problems of missing data. However, there was no consistent significant effect for swell on these catch rates. The cross correlations of the season 1992/1993 and the season 1995/1996 have some significant values at some different lags while those of the season 1996/1997 do not show any significant values at all.

Some plots of adjusted catch rates against values of the swell were created to ensure the assumption of a linear relationship between both series. Graphs of adjusted catch rates against the swell values at lag –1 for the shallow data sets of the season 1998/1999 in Zone B and Zone C are illustrated in Figure 4.11. They clearly indicate some linear relationships in both data sets.

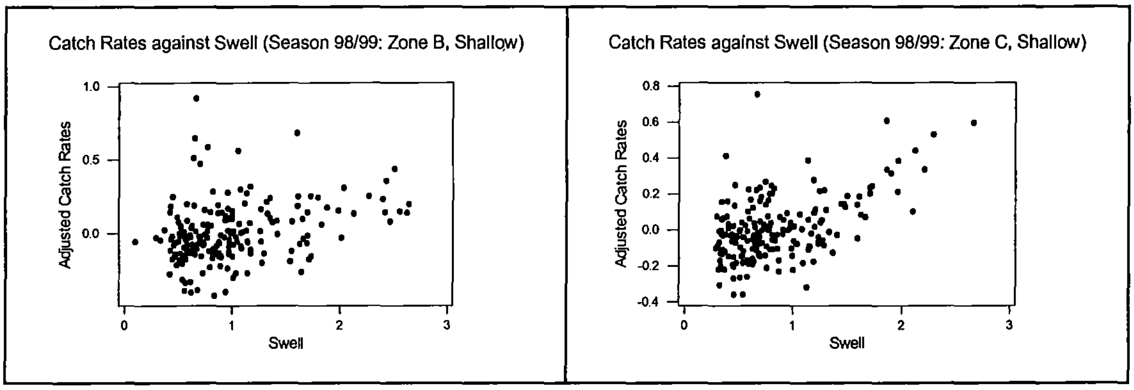


Figure 4. 11: Graphs of the adjusted catch rates against the swell values at lag –1 for the shallow data sets of the season 1998/1999 in Zone B and Zone C.

Further investigation of the relationship between catch rates and swell was undertaken by separating the catch rates in Zone B and Zone C into two parts, whites and reds, and calculating the cross correlations for each of these data sets. The significant values of the cross correlations during the period of reds seem to be higher than those during the whole period of the season. However, the results show that the significant effects for swell on catch rates for the whole season and on the catch rates for the period of reds are almost identical because the cross correlations of the data have similar significant lags. On the other hand, the outcomes for the period of whites are quite different from those for the whole season and the period of reds in Zone B and Zone C. Figure 4.12 illustrates the similarity and the difference of the cross correlations for the whole season, the period of whites, and the period of reds in Zone C for the season 1993/1994.

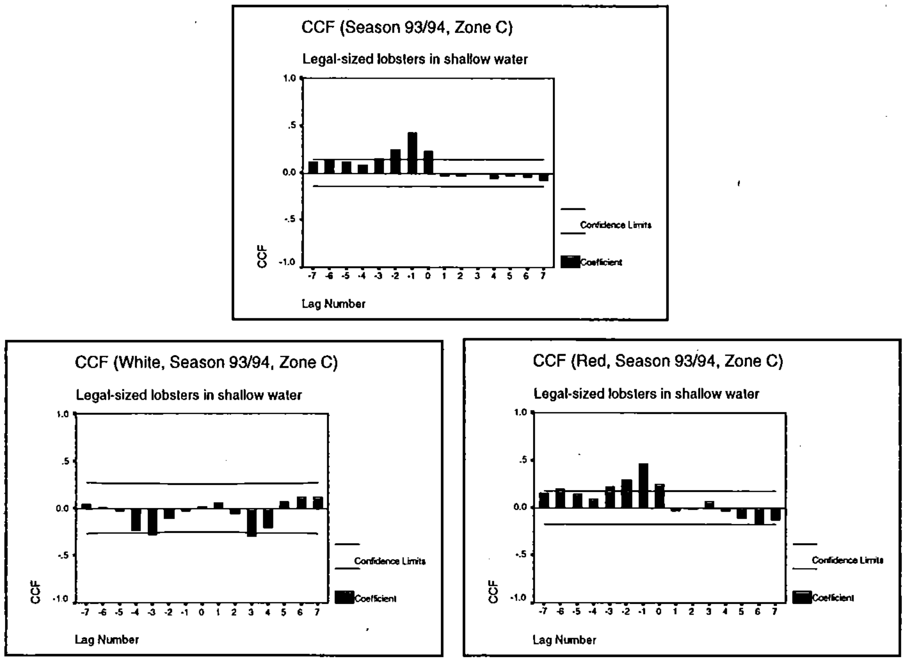


Figure 4. 12: Cross correlations of the adjusted catch rates of legal sized lobsters in shallow water with the swell in Zone C for the whole season 1993/1994 including the periods of whites and reds.

The cross correlations for period of whites in all fishing seasons do not have strong significant values at any specific lags for any categories. Although a few significant values appear in some results in Appendix F, there is no overall evidence of the swell impact on the catch rates of whites because the significant values do not appear for most of the seasons considered.

In addition, the problem of estimating cross correlation functions, mentioned in section 3.2, was examined. Consequently, the white noise for each series of the catch rates and the swell was calculated using ARIMA models. Then, the cross correlation functions of these purely random series were computed. It is noted that only the residuals of catch rates for the full fishing season are considered in this state. This is because the previous investigation has already shown that the swell does not seem to have an effect on whites, and the catch rates for the period of reds have the similar correlation to those for the whole season with the swell. Due to the large number of the results, only the cross correlation functions showing the effects of the swell on the catch rates are given in Appendix G and those corresponding to the results in Figure 4.12 are shown in Figure 4.13.

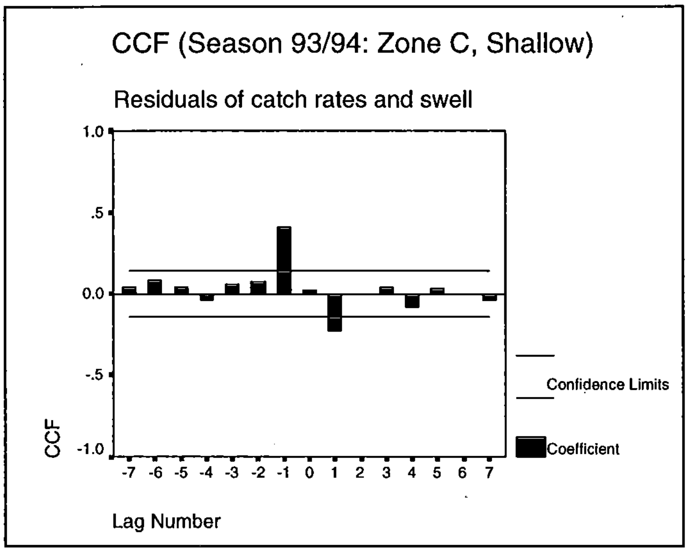


Figure 4. 13: Cross correlations of the residuals for the catch rates of legal sized lobsters in shallow water with the swell in Zone C for the whole season 1993/1994.

These cross correlation functions support the earlier results given for catch rates and swell for deep data in Zone A and for both shallow and deep data in Zone B and Zone C which correlated at lag – 1. Moreover, the cross correlations of the purely random series for undersized catch rates and swell in Zone B illustrated that swell probably has a negative impact on the undersized catch rates on the day of the catch (the cross correlation coefficients were significant at lag 0).

In conclusion, the swell seems to have an impact on the catch rates of legal sized lobsters. The swell on the day before the catch has a positively significant correlation on the catch rates of the deep series in Zone A and the shallow and deep series in Zone B and C. The reason for this positive correlation may be the fact that the swell disturbs the bottom and increases the availability of food and also provides greater protection in terms of increased turbidity. Thus, legal sized lobsters can be more active and hence more easily caught when the swell occurs.

The swell also has a great impact during the reds season, as this is the period when the rock lobsters are sedentary. Hence, the swell increases their activity as described above. During the migration whites phase, many lobsters are already active, moving from shallow water to deep water, so there is no clear evidence of increased benefit of the swell on their activity level.

However, the swell also appears to have a negative correlation on the catch rates of undersized lobsters in Zone B on the day of the catch. This might be explained by the fact that undersized lobsters normally stay around inshore reefs. When the swell occurs, fishers do not fish close to these areas, so the catchability of these lobsters probably reduce during this time.

4.4 Temperature

The impact of water temperature on catch rates was also investigated in this study. However, due to the unavailability of the temperature data as mentioned in section 1.4.2, only catch rates for the fishing season 1992/1993 and the fishing season 1993/1994 were examined. Temperatures for different areas in fishing zones B and C were used. In addition, the temperature data were only available for short time periods with different starting and finishing times. In order to explore the relationship between the catch rate and temperature, the trend of the catch rate was obtained by using 30 point centred moving averages of the original catch rates for both data sets. The cross correlation functions between the original catch rates, the trend of the catch rates, the detrended catch rates, and the adjusted catch rates and the temperature data at the sites representing the fishing zone A (Rat Island), the fishing zone B (South Passage and Seven Mile Beach), and the fishing zone C (Jurien Bay, Alkimos, Warnbro Sound, and Cape Mentelle) were carried out.

The results from the cross correlation functions of the detrended catch rates and the adjusted catch rates with water temperature (not shown here due to the large number of the outcomes) did not provide any highly significant correlations at any specific time lags. It was also noted that the cross correlation functions for the sites South Passage and Seven Mile Beach for Zone B and Jurien Bay, Alkimos, Warnbro Sound, and Cape Mentelle for Zone C had different patterns for the same zone and the same fishing season. For example, Figure 4.14 shows that some significant values appear in the cross correlation function for the season 1992/1993 in Jurien Bay, but there is no significant value in the cross correlation function for the same fishing season in Warnbro Sound. This provides evidence that the effect of temperature on the catch rate at a particular site may only be evident in a localized region surrounding the site.

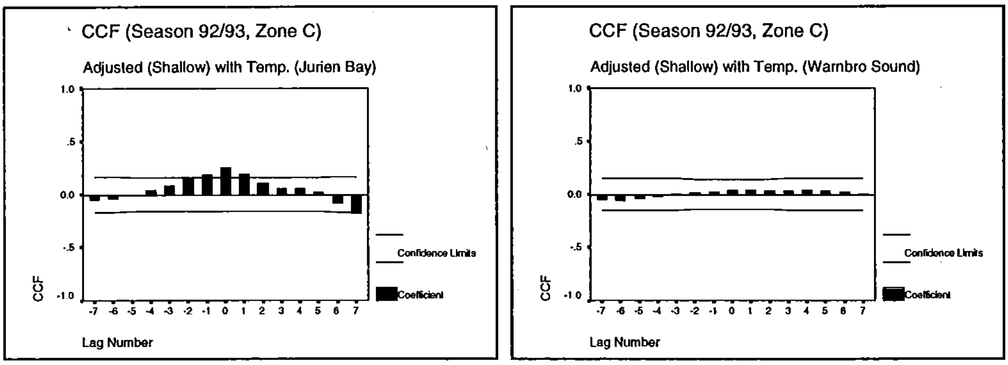


Figure 4. 14: Comparison between the cross correlation functions for the adjusted catch rates in two different sites, Jurien Bay and Warnbro Sound, of the same zone and the same season.

In addition, the results of the cross correlation functions between the original catch rate and the trend and the temperature for Zone B and Zone C (not shown in this thesis) did not indicate any evidence of the influence of temperature on catch rates. The problems of different patterns in different sites, as in the cross correlation functions for the detrended and adjusted catch rates, also occur here. Figure 4.15 illustrates the different patterns of the cross correlation functions between the trend and the temperature from different areas.

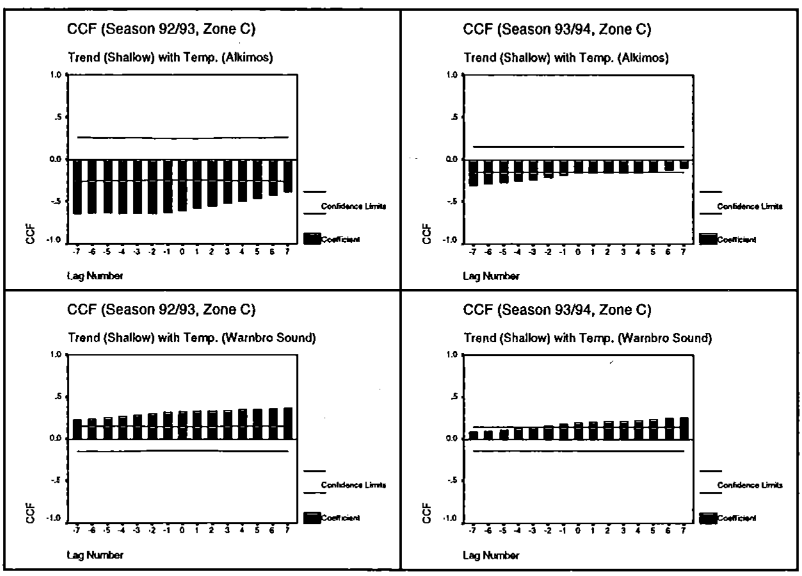


Figure 4. 15: Comparison of the cross correlation functions between the trend and the temperature for two different areas, Alkimos and Warnbro Sound, in both 1992/1993 and 1993/1994 seasons.

Unlike the above results, the cross correlation functions of original catch rates or trend and temperature at Rat Island in Zone A for both seasons had similar patterns with both the temperature and the trend decreasing with time. This is probably due to the shorter period used for the fishing season in Zone A. In this thesis, only the cross correlation functions of the trend and the temperature at Rat Island are shown since these cross correlation functions are similar to those between the original catch rate and the swell. Figure 4.16 illustrates some examples of cross correlation functions for legal sized lobsters. However, the graphs in Figure 4.17 indicate how the trend of the catch rates and the temperature decrease over both fishing seasons. Thus, the high correlations here are likely to be caused by the downward trend in the two data sets.

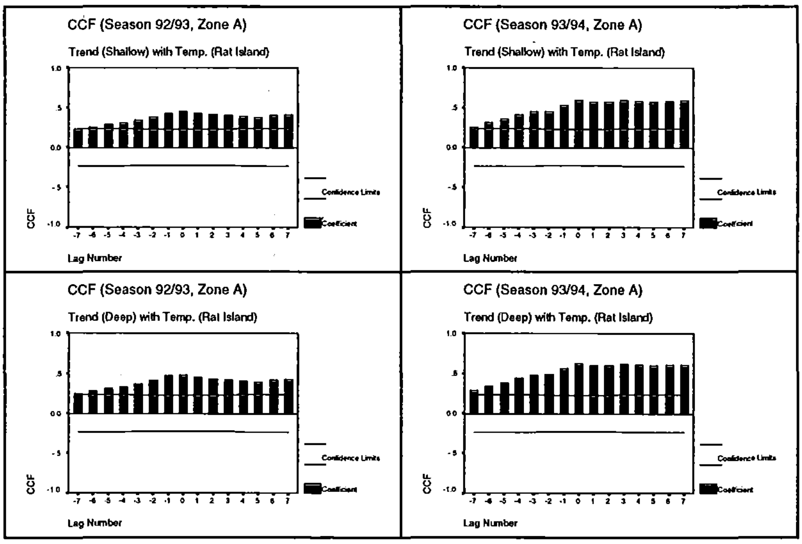


Figure 4. 16: Cross correlation functions between the trend and the temperature at Rat Island in Zone A for legal sized lobsters of the season 1992/1993 and the season 1993/1994.

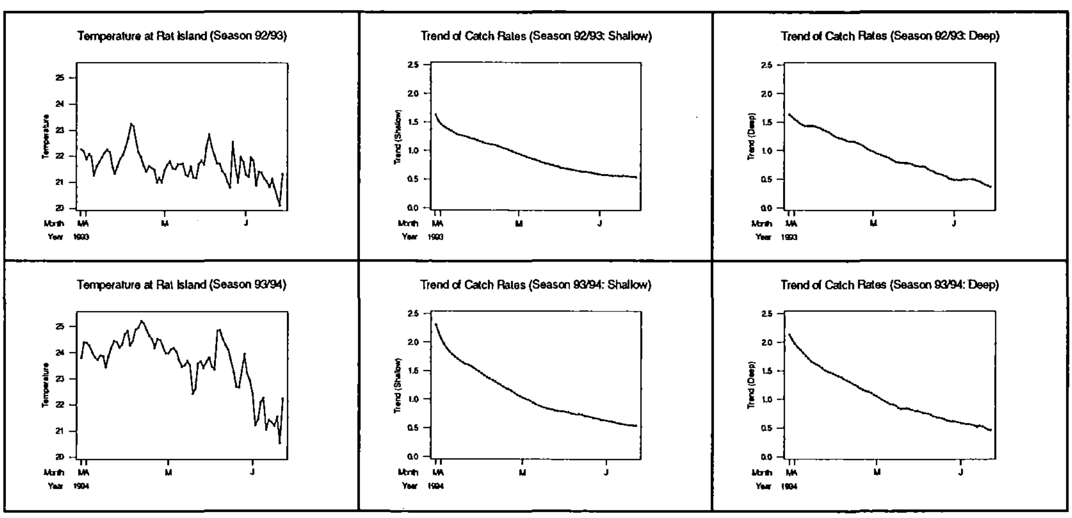


Figure 4. 17: Graphs for the temperature at Rat Island and the trend of the shallow and deep series in Zone A for both 1992/1993 and 1993/1994 seasons.

Further investigation indicates that both the trend and the temperature are autocorrelated. This examines the effect of the daily variation in water temperatures on catch rates as compared to the monthly trend in catch rates and water temperatures. Therefore, the cross correlation functions between the residuals of the trend and the residuals of the temperature should be carried out to investigate the actual correlations between the data. The results do not show any significant values at any lags. For instance, the cross correlation functions between the residuals of the trend and those of the temperature for legal sized catch rates at Rat Island are given in Figure 4.18. Thus, there is no evidence of a water temperature impact on the daily catch rates given the data obtained in this study. However, the effect of the monthly variation in water temperatures on catch rates is confounded with the decline in the catch rates by the effect of fishing.

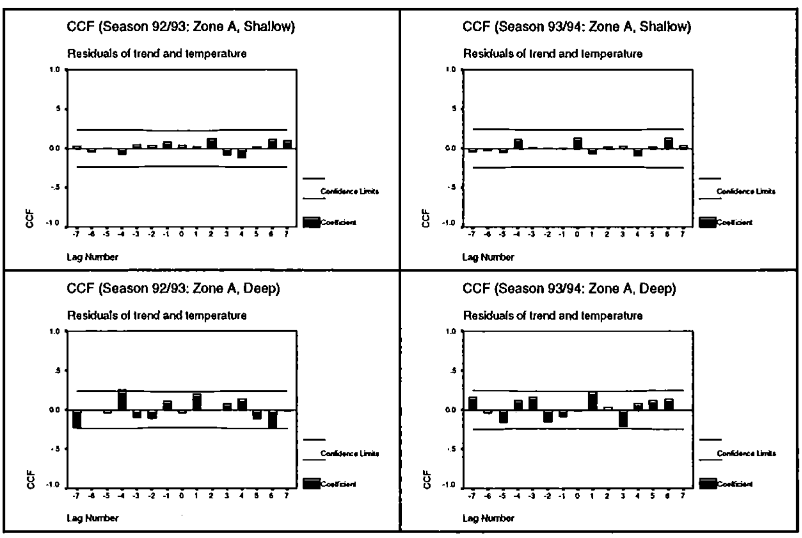


Figure 4. 18: Cross correlation functions between the residuals of the trend and those of the temperature at Rat Island in Zone A for legal sized lobsters of the season 1992/1993 and the season 1993/1994.

CHAPTER 5: *TIME SERIES MODELLING*

In the previous chapter, it was observed that swell has an effect on the daily catch rates for many zones and categories. Therefore, appropriate time series models are introduced in this chapter in order to identify these relationships. ARIMA models of catch rates and swell series are outlined in section 5.1 to explain the behaviour of these data sets. Regression models and transfer function models fitted between the catch rates and swell are respectively presented in sections 5.2 and 5.3.

5.1 ARIMA Models

In order to identify the characteristics of all series for proposed models, the data sets of the adjusted catch rates and those for the associated swell were examined using ARIMA models. Only the data for the whole period of the season were considered for modelling as the cross correlation functions for the period over the full fishing season and for the period of reds were quite similar while those for the period of whites do not show any significant coefficients. Therefore, only the series for the period over the full fishing season of legal sized lobsters in deep water for Zone A, those of legal sized lobsters in both shallow and deep water for Zone B and Zone C, and those of undersized lobsters for Zone B were fitted.

Autocorrelation and partial autocorrelation functions were calculated for each series in order to determine orders for the autoregressive and moving average processes. For example, Figure 5.1 shows the ACF and the PACF for the shallow series of the adjusted catch rates in Zone B for the season 1994/1995. The AR(1) process was identified as a suitable model for the series because the ACF dies out in an exponential or sinusoidal fashion while the PACF cuts off after lag 1. In addition, the Minitab output of an appropriate model for the data set given in Table 5.1 confirmed these results.

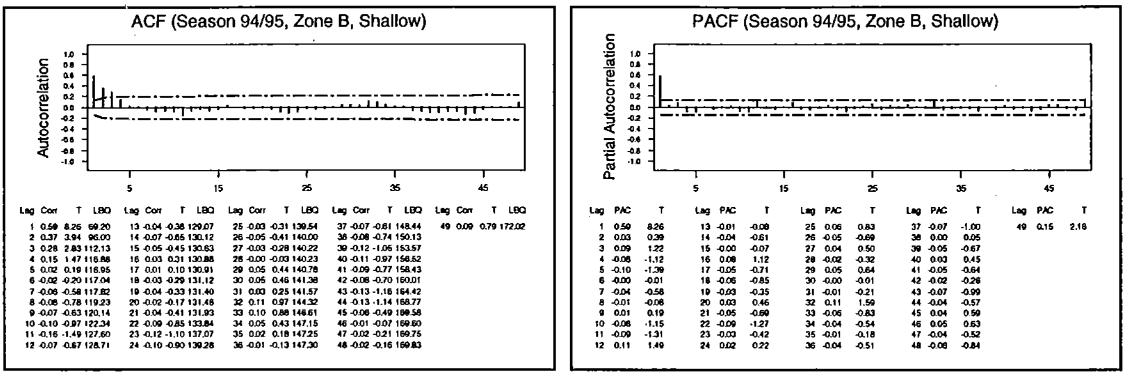


Figure 5. 1: Autocorrelation and Partial autocorrelation functions for the shallow series of the adjusted catch rates in Zone B for the season 1994/1995.

Table 5. 1: Minitab output AR(1) for the shallow adjusted catch rates of the season 1994/1995 in Zone B.

ARIMA Model: Adjusted Catch Rates (94/95: Zone B, Shallow)

```
ARIMA model for adjusted catch rates (94/95: Zone B, Shallow)

Final Estimates of Parameters
Type          Coef     SE Coef        T        P
AR   1      0.6019      0.0573    10.50    0.000

Number of observations:  196
Adjusted catch rates:      SS =  4.98192  (backforecasts excluded)
                           MS = 0.02555  DF = 195

Modified Box-Pierce (Ljung-Box) Chi-Square statistic
Lag                12        24        36        48
Chi-Square       12.6      20.7      28.8      39.9
DF                 11        23        35        47
P-Value         0.322     0.597     0.759     0.758
```

By using the software package Minitab, the appropriate ARIMA models for all series were estimated. It is noted that an autoregressive process was preferable to a moving average process even though a MA process is normally considered to be simpler because an AR process provides a better explanation for the models. Table 5.2 shows the fitted model for each examined data set.

The preliminary analysis of the series undertaken by using ARIMA models (See Table 5.2) shows that most of the data sets for the adjusted catch rates and the swell can be fitted by the autoregressive process of the first order or the AR(1) process, especially the series in Zone B and Zone C. This means that the current value of the adjusted catch rates and the swell in Zone B and Zone C, X_t, can be approximately explained as a function of the past value, X_{t-1}. However, almost all deep series of the adjusted catch rates and one of the swell for legal sized lobsters in Zone A can be explained by the white noise process or the moving average process of the first order, the MA(1) process. The present value of the series is thus assumed to be either a random or a linear combination of the white noise at the present time and the one before, Z_t and Z_{t-1}.

Table 5. 2: Appropriate ARIMA models for all of the time series considered for proposed models.

Season	Zone	Swell	Depth	Adjusted
92/93	A	AR (1)	Deep	MA (1)
	C	ARIMA (1,0,1)	Shallow	AR (1)
			Deep	AR (1)
93/94	A	MA (1)	Deep	MA (2)
	B	ARIMA (1,0,2)	Shallow	ARIMA (1,0,1)
			Deep	AR (1)
			Undersize	AR (1)
	C	AR (1)	Shallow	AR (1)
94/95	B	ARIMA (1,0,1)	Shallow	AR (1)
			Deep	AR (1)
			Undersize	AR (1)
95/96	A	AR (1)	Deep	White noise
	B	AR (1)	Shallow	AR(1)
			Deep	AR (1)
			Undersize	AR (1)
	C	AR (1)	Shallow	AR (1)
			Deep	MA (2)
96/97	A	AR (1)	Deep	MA (1)
	B	AR (1)	Shallow	AR (1)
			Deep	AR (1)
			Undersize	AR (1)
	C	AR (1)	Shallow	AR (1)
			Deep	ARIMA (1,0,1)
97/98	A	AR (1)	Deep	MA (1)
	B	AR (1)	Shallow	AR (1)
			Deep	AR (1)
			Undersize	AR (1)
	C	AR (1)	Shallow	AR (1)
			Deep	ARIMA (1,0,1)
98/99	A	AR (1)	Deep	White noise
	B	AR (1)	Shallow	AR (1)
			Deep	MA (2)
	C	AR (1)	Shallow	AR (1)
			Deep	AR (1)

5.2 Regression Models

To start investigating the relationship between catch rates and swell for each series, basic linear regression models were used. From section 4.3, it is clear that swell does have an effect on catch rates on the day before the catch for the legal sized data in Zone A, Zone B and Zone C and at the day of the catch for the undersized data in Zone B. Moreover, the swell two days before the catch also seems to have the impact on the catch rates for some data sets. The response variable, Y_t, for each series was taken to be the adjusted catch rates. Three explanatory variables, X_t, X_{t-1}, and X_{t-2}, where used which were the swell at the present time and the swell on day and two days before the catch. In practice, almost any statistical software package can be used to estimate regression model coefficients (though not standard error); the outputs presented here were obtained by using Minitab. For instance, the Minitab output of the shallow data set for the season 1993/1994 in Zone C is given as follows.

Table 5. 3: Regression model for the shallow series of the season 1993/1994 in Zone C.

Regression Analysis: Y_t versus X_t, X_{t-1}, and X_{t-2}

The regression equation is

$$Y_t = -0.123 - 0.0300 X_t + 0.179 X_{t-1} - 0.0218 X_{t-2}$$

Predictor	Coef	SE Coef	T	P
Constant	-0.12308	0.02696	-4.57	0.000
X_t	-0.03004	0.02936	-1.02	0.308
X_{t-1}	0.17869	0.03627	4.93	0.000
X_{t-2}	-0.02184	0.02937	-0.74	0.458

S = 0.1573 R-Sq = 18.8% R-Sq(adj) = 17.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1.09704	0.36568	14.78	0.000
Residual Error	192	4.74949	0.02474		
Total	195	5.84653			

Assuming for the moment that model residuals have satisfactory diagnostics, the p-values and t-values in Table 5.3 show that the swell at two days before the catch (X_{t-2}) was the most insignificant variable for the series. Thus, we can delete this variable from the above model. Table 5.4 illustrates the Minitab output for the new model after removing the variable X_{t-2}.

Table 5. 4: Regression model from Table 5.3 after removing the variable X_{t-2}.

Regression Analysis: Y_t versus X_t and X_{t-1}

The regression equation is
$Y_t = - 0.131 - 0.0270\ X_t + 0.163\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13099	0.02475	-5.29	0.000
X_t	-0.02702	0.02905	-0.93	0.353
X_{t-1}	0.16257	0.02904	5.60	0.000

S = 0.1571 R-Sq = 18.5% R-Sq(adj) = 17.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.08336	0.54168	21.95	0.000
Residual Error	193	4.76317	0.02468		
Total	195	5.84653			

From the p-value and the t-value of the explanatory variable X_t in Table 5.4, it is also clear that the swell on the present day (X_t) was not significant for the model. As a result, this variable was removed. The final model for the shallow series of the season 1993/1994 in Zone C is a simple regression model, and it is given in Table 5.5.

Table 5. 5: Final regression model for the shallow series of the season 1993/1994 in Zone C.

Regression Analysis: Y_t versus X_{t-1}

The regression equation is
$Y_t = - 0.140 + 0.145\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13960	0.02294	-6.08	0.000
X_{t-1}	0.14506	0.02211	6.56	0.000

S = 0.1570 R-Sq = 18.2% R-Sq(adj) = 17.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.0620	1.0620	43.06	0.000
Residual Error	194	4.7845	0.0247		
Total	195	5.8465			

Regardless of the residual diagnostics the small change in R-squared in dropping X_t, X_{t-2} allows us to restrict our attention to relationship between Y_t and X_{t-1}. The correlation matrix of the explanatory variables is given below. The correlations in Table 5.6 shows that the explanatory variables, X_t, X_{t-1}, and X_{t-2}, were high correlated, so some singularity problems of the variables may occur for the regression model. Further investigation of the correlation matrixes for the series considered for modelling was undertaken. The results (not displayed here) show that the three explanatory variables in each data set were high correlated.

Table 5. 6: Correlation matrix of the three explanatory variables for the season 1993/1994 in Zone C.

CORRELATION MATRIX OF EXPLANATORY VARIABLES

X_t	1.000		
X_{t-1}	0.648	1.000	
X_{t-2}	0.340	0.649	1.000
	X_t	X_{t-1}	X_{t-2}

Almost all of the models, after removing the insignificant variables, showed the relationships between catch rates and swell which corresponded to the results in section 4.3. In addition, the effects of the swell on the present day and two days before the catch for legal sized data and those for one day and two days before the catch for undersized data in Zone B did not have consistent and strong effects on catch rates. Consequently, these variables can be excluded from the models. The variable X_{t-1} therefore becomes the only independent variable considered for the regression models of the legal sized data, and the variable X_t is the only explanatory variable considered for the models of the undersized data in Zone B. Models for all investigated data sets are given in Table 5.7 and the Minitab output for these models are shown in Appendix H.

All models presented in the following table show the same pattern with negative constants and positive coefficients for the variable X_{t-1} in the models for the legal sized data and with positive constants and negative coefficients for the variable X_t in the models for the undersized data in Zone B. Moreover, these models correspond to the results of the cross correlation functions given before. Although both the constants and the coefficient values for the models are not high, the R^2 values for most of the models are quite low. As a result, even before we examine the diagnostics for the residuals, the fitted regression models in this stage may not be the most appropriate models for the data.

However, the R^2 value is not always reliable as a measure of the adequacy of a model since the difference in the R^2 values of two different fitted models may be due to variation in the response variables and not variation in the residual series. Therefore, the

R^2 values for the different models can be quite different even though the residual series for each fitted model are practically identical. For diagnostic checks of the model, the residual values for all of the models should be investigated. The model can only be considered satisfactory when the residual series is approximately random.

Table 5. 7: Regression models with the response variable Y_t (the adjusted catch rates) and the explanatory variable X_{t-1} (the swell on the day before the catch) for legal sized data or the explanatory variable X_t (the swell on the day of the catch) for undersized data.

Zone	Depth	Season	Constant	Coefficient	R-square
A	Deep	92/93	−0.223	0.188	9.2
		93/94	−0.147	0.110	7.3
		95/96	−0.140	0.114	22.5
		96/97	−0.174	0.117	9.1
		97/98	-----	-----	-----
		98/99	-----	-----	-----
B	Shallow	93/94	−0.115	0.101	5.7
		94/95	−0.153	0.150	16.3
		95/96	−0.090	0.093	7.5
		96/97	−0.185	0.175	17.9
		97/98	−0.065*	0.063	2.7
		98/99	−0.113	0.118	9.2
	Deep	93/94	−0.365	0.339	9.7
		94/95	-----	-----	-----
		95/96	−0.197	0.196	4.2
		96/97	-----	-----	-----
		97/98	-----	-----	-----
		98/99	−0.190	0.202	4.1
	Undersize	93/94	-----	-----	-----
		94/95	0.073	−0.073	4.7
		95/96	-----	-----	-----
		96/97	-----	-----	-----
		97/98	0.090	−0.087	5.8
C	Shallow	92/93	−0.099	0.134	7.0
		93/94	−0.140	0.145	18.2
		95/96	−0.135	0.159	13.0
		96/97	−0.189	0.206	22.9
		97/98	−0.134	0.149	17.4
		98/99	−0.165	0.201	27.5
	Deep	92/93	−0.212	0.268	6.1
		95/96	-----	-----	-----
		96/97	−0.118	0.125	3.1
		97/98	−0.125	0.132	2.7
		98/99	−0.292	0.363	21.5

i) ----- shows that there is no relationship between the response and the explanatory variables.
ii) The symbol * means that the variable is not significant for the model (the p-value is less than 0.05 or the t-value is in the interval from −2.15 to 2.15).

Further inquiry into the residuals from the regression models given above indicated that almost all of the error terms for these models were not independent white noise sequences. The autocorrelation functions of the residuals are given in Appendix I. The graphs in the appendix illustrate that almost all residuals from the models are autocorrelated. For example, the autocorrelation functions of the residuals from some different models in Zone A, Zone B, and Zone C are illustrated in Figure 5.2.

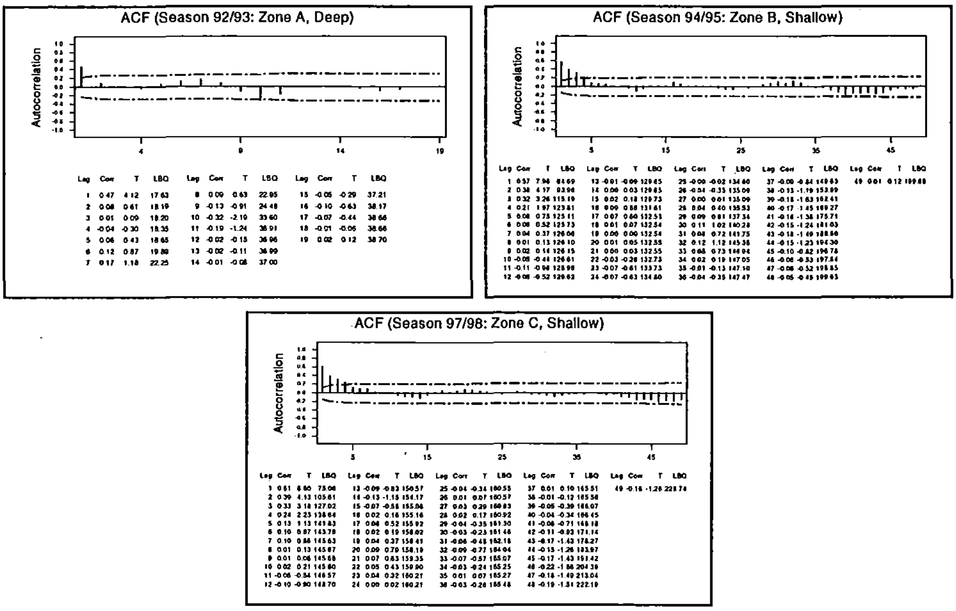


Figure 5. 2: Autocorrelation functions of the residuals from regression models for the deep series of the season 1992/1993 in Zone A, the shallow series of the season 1994/1995 in Zone B, and the shallow series of the season 1997/1998 in Zone C.

These autocorrelation functions confirm that more suitable models are required to fit the relationships between adjusted catch rates and swell. From the preliminary analysis using ARIMA models, it is quite clear that most of the data sets can be explained by the AR(1) process. Thus, including the first autoregressive term (Y_{t-1}), that is the past values of the adjusted catch rates, Y_t, as an explanatory variable in each model given in Table 5.7, would probably improve the model in terms of goodness-of-fit. As an example, the regression model and the ACF and PACF for the residuals of the shallow series for the season 1993/1994 in Zone C with the response variable, Y_t, and the explanatory variables, X_{t-1} and Y_{t-1}, are given as follows.

Table 5. 8: Regression model with Y_t versus X_{t-1} and Y_{t-1} for the shallow series of the season 1993/1994 in Zone C.

Regression Analysis: Y_t versus X_t and Y_{t-1}

The regression equation is
$Y_t = - 0.118 + 0.124 X_{t-1} + 0.275 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11843	0.02249	-5.27	0.000
X_{t-1}	0.12380	0.02171	5.70	0.000
Y_{t-1}	0.27519	0.06341	4.34	0.000

S = 0.1503 R-Sq = 25.4% R-Sq(adj) = 24.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.48741	0.74370	32.93	0.000
Residual Error	193	4.35913	0.02259		
Total	195	5.84653			

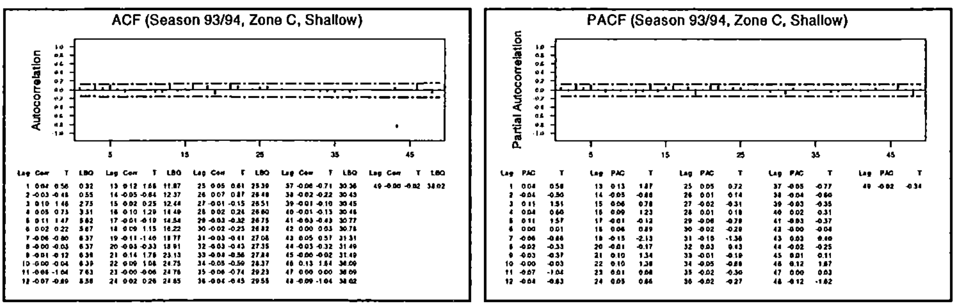


Figure 5. 3: ACF and PACF of the residuals from the regression model with Y_t versus X_{t-1} and Y_{t-1} for the shallow series of the season 1993/1994 in Zone C.

The R^2 value for the new model increases from 18.2% to 25.4%, and the model seems to fit well because the residual series appears to be a white noise process (no anomalies are apparent in the ACF and PACF). Fitted models with the response variable, Y_t, and the explanatory variables, X_{t-1} and Y_{t-1}, for each data set considered for modelling are indicated in Table 5.9. The Minitab outputs of the models and the autocorrelation functions for the residuals are given in Appendices I and J.

The new R^2 values in Table 5.9 and the autocorrelation functions of the residuals show that the new fitted models are more appropriate than the models without the variable Y_{t-1}. All of the R^2 values for the models with the explanatory variable Y_{t-1} are higher than those without the variable, and almost all of the autocorrelation functions in Appendix K illustrate that the residuals for each model are compatible with a white noise process.

Table 5. 9: Regression models with the response variable, Y_t, and the explanatory variables, X_{t-1} for legal sized data or X_t for undersized data in Zone B and Y_{t-1}.

Zone	Depth	Season	Constant	Coefficient(1)	Coefficient(2)	R-square
A	Deep	92/93	– 0.122*	0.105*	0.454	27.2
		93/94	– 0.150	0.112	– 0.013*	7.3
		95/96	– 0.133	0.108	0.054*	22.7
		96/97	– 0.144	0.101	0.345	21.1
		97/98	– 0.031*	0.037*	0.348	13.2
		98/99	-----	-----	-----	-----
B	Shallow	93/94	– 0.092	0.081	0.433	25.3
		94/95	– 0.104	0.103	0.533	43.2
		95/96	– 0.067	0.068	0.546	37.3
		96/97	– 0.143	0.139	0.508	43.3
		97/98	– 0.050*	0.047	0.576	36.1
		98/99	– 0.087	0.090	0.643	50.0
	Deep	93/94	– 0.286	0.265	0.327	20.0
		94/95	– 0.045*	0.047*	0.523	28.0
		95/96	– 0.156	0.156	0.281	11.8
		96/97	– 0.133	0.121	0.391	17.7
		97/98	– 0.014*	0.009*	0.590	34.4
		98/99	– 0.133*	0.142	0.302	12.9
	Undersize	93/94	0.018*	– 0.017*	0.464	21.6
		94/95	0.060	– 0.060	0.301	13.5
		95/96	0.025*	– 0.025*	0.433	19.6
		96/97	0.016*	– 0.020*	0.423	18.6
		97/98	0.061	– 0.060	0.397	21.0
C	Shallow	92/93	– 0.077	0.102	0.415	25.1
		93/94	– 0.118	0.124	0.275	25.4
		95/96	– 0.098	0.113	0.446	31.3
		96/97	– 0.147	0.162	0.366	35.3
		97/98	– 0.087	0.095	0.511	41.8
		98/99	– 0.132	0.161	0.274	33.9
	Deep	92/93	– 0.128	0.162	0.535	34.7
		95/96	-----	-----	-----	-----
		96/97	– 0.105	0.111	0.244	8.9
		97/98	– 0.117	0.123	0.499	28.8
		98/99	– 0.263	0.327	0.135*	23.1

i) Coefficient(1) is the coefficient values of X_{t-1} for legal sized data or the coefficient values of X_t for undersized data in Zone B.
ii) Coefficient(2) is the coefficient values of Y_{t-1}.
iii) ----- means that none of variables for that model are significant.
iv) The symbol * means that the variable is not significant for the model (the p-value is less than 0.05 or the t-value is in the interval from – 2.15 to 2.15).

5.3 Transfer Function Models

Another class of models called transfer function models was used to model the relationships between the adjusted catch rates and the swell. The results were provided by using the SCA software package. These models allow users to relate the values of an output series with its own past values and the past and present values of input series. The output series, Y_t, here contains the values of the adjusted catch rates and the input series, X_t, contains the values of the swell.

From previous results of the cross correlation functions in section 4.3, the swell at lag −1 and lag 0 seems to have main effects on the catch rates of legal sized lobsters and on those of undersized lobsters in Zone B respectively. In addition, the swell at lag −2 has an impact on the catch rates for some data sets. Therefore, only three impulse response weights (transfer function weights or ν-weights) have been considered for each linear transfer function model. In addition, an AR(1) process was first approximated for representing the disturbance term since there was no existing seasonality. For example, the SCA output of the transfer function model for the shallow data set of the season 1997/1998 in Zone B is shown in Table 5.10. The variables C9798SH and C9798SW here are the output series (Y_t) and the input series (X_t) for this data set. The model can be defined as the following equation.

$$Y_t = -0.060 - 0.045X_t + 0.102X_{t-1} - 0.005X_{t-2} + \frac{1}{1-0.593B}a_t$$

Table 5. 10: Transfer function model for the shallow data set of the season 1997/1998 in Zone B.

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN    1  THRU  196

 NONLINEAR ESTIMATION TERMINATED DUE TO:
 RELATIVE CHANGE IN (OBJECTIVE FUNCTION)**0.5 LESS THAN 0.1000D-02

 SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BSH

 -----------------------------------------------------------------------
 VARIABLE    TYPE OF    ORIGINAL     DIFFERENCING
            VARIABLE   OR CENTERED

 B9798SH     RANDOM     ORIGINAL     NONE

 B9798SW     RANDOM     ORIGINAL     NONE
 -----------------------------------------------------------------------

  PARAMETER   VARIABLE  NUM./  FACTOR  ORDER   CONS-      VALUE      STD      T
    LABEL       NAME    DENOM.                 TRAINT                ERROR   VALUE

  1  CONST              CNST      1      0      NONE     -.0595     .0563  -1.06
  2    V0    B9798SW    NUM.      1      0      NONE     -.0446     .0303  -1.47
  3    V1    B9798SW    NUM.      1      1      NONE      .1019     .0309   3.30
  4    V2    B9798SW    NUM.      1      2      NONE     -.0046     .0304   -.15
  5          B9798SH    D-AR      1      1      NONE      .5927     .0576  10.29

 TOTAL SUM OF SQUARES . . . . . . . .  0.791915E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .           196
 RESIDUAL SUM OF SQUARES. . . . . . .  0.481668E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .           193
 R-SQUARE . . . . . . . . . . . . . .         0.382
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.249569E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.157978E+00
```

Before using the results from the model given above, the irregularity of the residual series was investigated to decide whether or not there were any discrepancies that still need to be corrected. It should be noted that a residual series is different from a disturbance series or an error term (N_t) from a transfer function model. The error term here follows an ARIMA model, and it is a part of the model while the residual series is the difference between the actual and the fitted values. Figure 5.4 illustrates the ACF of the residuals from the model in Table 5.10. The figure indicates that the residuals are compatible with an independent white noise sequence. Therefore, the results from this model are sensible.

```
AUTOCORRELATIONS

           -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
             +----+----+----+----+----+----+----+----+----+----+
                                      I
 1  -0.03                         +  XI    +
 2  -0.01                         +   I    +
 3   0.00                         +   I    +
 4   0.11                         +   IXXX+
 5   0.01                         +   I    +
 6   0.02                         +   I    +
 7  -0.04                         +  XI    +
 8   0.07                         +   IXX  +
 9   0.01                         +   I    +
10  -0.09                         + XXI    +
11  -0.03                         +  XI    +
12  -0.11                         +XXXI    +
13   0.01                         +   I    +
14  -0.08                         + XXI    +
15  -0.17                         XXXXXI   +
16   0.00                         +   I    +
17  -0.01                         +   I    +
18   0.04                         +   IX   +
19   0.07                         +   IXX  +
20  -0.01                         +   I    +
21   0.03                         +   IX   +
22   0.00                         +   I    +
23   0.00                         +   I    +
24  -0.02                         +  XI    +
```

Figure 5. 4: ACF of the residuals from the model given in Table 5.10.

The t-values of ν-weights indicate that the coefficients for the present values and the past values at lag –2 are not significantly different from zero (t-values are greater than –2.15 but less than 2.15). Therefore, the following model should be more suitable for the data set.

$$Y_t = \alpha + (\nu_1 B)X_t + N_t$$

To determine the disturbance term, the ACF and PACF of the disturbance series of the model in Table 5.10, which is stored in a defined variable by using an SCA command, were computed. The SCA results for these functions are given below.

```
AUTOCORRELATIONS

           -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
             +----+----+----+----+----+----+----+----+----+----+
                                      I
  1   0.59                        +   IXXX+XXXXXXXXXXX
  2   0.38                        +   IXXXX+XXXX
  3   0.28                        +   IXXXX+XX
  4   0.24                        +   IXXXX+X
  5   0.16                        +   IXXXX+
  6   0.11                        +   IXXX +
  7   0.06                        +   IX   +
  8   0.06                        +   IX   +
  9  -0.01                        +   I    +
 10  -0.10                       + XXXI    +
 11  -0.14                       + XXXI    +
 12  -0.18                       XXXXXI    +
```

```
 PARTIAL AUTOCORRELATIONS

           -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
             +----+----+----+----+----+----+----+----+----+----+
                                      I
  1   0.59                        +   IXXX+XXXXXXXXXXX
  2   0.04                        +   IX  +
  3   0.06                        +   IXX +
  4   0.08                        +   IXX +
  5  -0.05                        +  XI   +
  6   0.00                        +   I   +
  7  -0.03                        +  XI   +
  8   0.03                        +   IX  +
  9  -0.09                        + XXI   +
 10  -0.11                        +XXXI   +
 11  -0.04                        +  XI   +
 12  -0.10                        + XXI   +
```

Figure 5. 5: ACF and PACF of the disturbance term (N_t) from the model in Table 5.10.

The ACF dies out in an exponential or sinusoidal pattern while the PACF cuts off after the first lag, so the pattern of N_t corresponds to the AR(1) process. However, the disturbance term was fitted following an AR(1) model, a MA(1) model, and an ARIMA(1, 0, 1) model. The results (not given here) demonstrated that all the considered models were appropriate for the disturbance series. However, the R^2 value of the transfer function model with the AR(1) process (37.4%) for the disturbance term was higher than that with the MA(1) process (29.4%). Moreover, the AR(1) model improved in terms of interpretation. Although the model with the disturbance term following the ARIMA(1, 0, 1) model also seemed to be suitable with its R^2 value equal to 37.6%, the model with disturbance term following the AR(1) process was less complicated, and both R^2 values for the two transfer function models were almost the same. As a result, the AR(1) model has been used here for the disturbance term. The transfer function model of the shallow data set for the season 1997/1998 in Zone B with the past values of the swell at lag –1 and the disturbance term following the AR(1) process is shown in Table 5.11.

Table 5. 11: Transfer function model for the shallow data set of the season 1997/1998 in Zone B with the explanatory variable X_{t-1} and the disturbance series following the AR(1) process.

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN    1  THRU  196

 NONLINEAR ESTIMATION TERMINATED DUE TO:
 RELATIVE CHANGE IN (OBJECTIVE FUNCTION)**0.5 LESS THAN 0.1000D-02

 SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BSH

 -----------------------------------------------------------------------
 VARIABLE    TYPE OF     ORIGINAL     DIFFERENCING
             VARIABLE   OR CENTERED

 B9798SH     RANDOM      ORIGINAL      NONE

 B9798SW     RANDOM      ORIGINAL      NONE
 -----------------------------------------------------------------------

  PARAMETER    VARIABLE  NUM./  FACTOR  ORDER   CONS-      VALUE       STD      T
    LABEL        NAME    DENOM.                TRAINT                 ERROR   VALUE

   1  CONST              CNST      1      0     NONE      -.1012      .0425   -2.38
   2    V1     B9798SW   NUM.      1      1     NONE       .0940      .0299    3.14
   3   PHI     B9798SH   D-AR      1      1     NONE       .5966      .0577   10.35

 TOTAL SUM OF SQUARES . . . . . . . .  0.791915E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .           196
 RESIDUAL SUM OF SQUARES. . . . . . .  0.490379E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .           194
 R-SQUARE . . . . . . . . . . . . . .         0.374
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.252773E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.158988E+00
```

The model given above can be rewritten as follows.

$$Y_t = -0.101 + 0.094X_{t-1} + \frac{1}{1-0.597B}a_t$$

At this state, the ACF of the residuals from the model given above was computed and shown in Figure 5.6. This ACF shows that the fitted model is not inappropriate because at least 19 out of 20 values of the autocorrelations lie within a 95% confidence limit of zero.

```
AUTOCORRELATIONS

           -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
             +----+----+----+----+----+----+----+----+----+----+
                                      I
  1  -0.03                         +  XI   +
  2  -0.01                         +   I   +
  3   0.01                         +   I   +
  4   0.09                         +   IXX +
  5   0.01                         +   I   +
  6   0.03                         +   IX  +
  7  -0.02                         +   I   +
  8   0.08                         +   IXX +
  9   0.02                         +   I   +
 10  -0.07                         + XXI   +
 11  -0.02                         +   I   +
 12  -0.11                         +XXXI   +
 13   0.03                         +   IX  +
 14  -0.07                         + XXI   +
 15  -0.17                         XXXXI   +
 16  -0.01                         +   I   +
 17  -0.01                         +   I   +
 18   0.02                         +   IX  +
 19   0.07                         +   IXX +
 20  -0.02                         +   I   +
 21   0.01                         +   I   +
 22   0.00                         +   I   +
 23  -0.02                         +   I   +
 24  -0.01                         +   I   +
```

Figure 5. 6: ACF of the residuals from the transfer function model given in Table 5.11.

Finally, the cross correlation function between the residuals of the model in Table 5.11 and those of the ARIMA model for the input series, that is the values of the swell for the season 1997/1998 in Zone B (See Table 5.2), was computed. The SCA output is illustrated in Figure 5.7. The output confirms that the transfer function model in Table 5.11 is not inadequate because it does not show any significant values at any lags. Therefore, this model can be chosen to represent the relationship between the adjusted catch rates and the swell in the shallow data set for the season 1997/1998 in Zone B.

```
CROSS CORRELATION

            -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
              +----+----+----+----+----+----+----+----+----+----+
                                       I
-12  -0.03                        +  XI    +
-11  -0.10                        +XXXI    +
-10   0.04                        +    IX  +
 -9  -0.02                        +    I   +
 -8   0.00                        +    I   +
 -7  -0.11                        +XXXI    +
 -6   0.03                        +    IX  +
 -5   0.02                        +    IX  +
 -4   0.04                        +    IX  +
 -3  -0.13                        +XXXI    +
 -2   0.01                        +    I   +
 -1   0.00                        +    I   +
  0  -0.10                        +XXXI    +
  1   0.03                        +    IX  +
  2  -0.04                        +   XI   +
  3   0.11                        +    IXXX+
  4   0.09                        +    IXX +
  5  -0.03                        +   XI   +
  6  -0.10                        +  XXI   +
  7  -0.11                        +XXXI    +
  8  -0.03                        +   XI   +
  9   0.04                        +    IX  +
 10  -0.09                        +  XXI   +
 11   0.00                        +    I   +
 12   0.09                        +    IXX +
```

Figure 5. 7: CCF between the residuals of the transfer function model in Table 5.11, RES, and the residuals of the input series (the swell for the season 1997/1998 in Zone B), RESSW.

By using the same processes, appropriate transfer function models for all data sets considered for modelling were calculated and are given in Table 5.12. It is noted that the general form for these models is given in equation (3.16). The SCA outputs for these models are demonstrated in Appendix L. Overall, the fitted transfer function models indicate that the swell on the day before the catch has a significant effect on the catch rates of legal sized lobsters in Zone A (only in deep water), Zone B, and Zone C. In addition, the catch rates of undersized lobsters in Zone B tend to have the opposite relationship with the swell at the day of the catch. The past values of the catch rates with one day lag seem to be the most important factor for the change of the catch rates in Zone B and Zone C. Unlike the results for Zone B and Zone C, the most significant variable for the catch rates in Zone A appear to be the irregularity in the catch rates.

Table 5. 12: Transfer function models for all considered data sets.

Zone	Depth	Season	Constant	V0	V1	V2	THETA1	THETA2	PHI1	R-square
A	Deep	92/93	-0.156*		0.139		-0.777			41.5
		93/94	-0.087		0.064			0.528		26.2
		95/96	-0.146		0.117					22.7
		96/97	-0.185		0.124		-0.339			18.9
		97/98	0.028*				-0.628			27.5
		98/99	----------	----------	----------	----------	----------	----------	----------	----------
B	Shallow	93/94	-0.111			0.093	0.409		0.742	27.0
		94/95	-0.163		0.155				0.565	45.5
		95/96	-0.123		0.114		0.281		0.764	43.2
		96/97	-0.209	-0.070	0.200	0.066			0.579	48.9
		97/98	-0.101		0.094				0.597	37.4
		98/99	-0.128		0.131				0.686	51.9
	Deep	93/94	-0.342		0.313				0.328	19.6
		94/95	-0.164*		0.159				0.551	29.7
		95/96	-0.238			0.228			0.256	14.3
		96/97	-0.188		0.162				0.380	18.3
		97/98	-0.021*						0.576	36.4
		98/99	-0.207		0.217		-0.294	-0.253		16.4
	Undersize	93/94	0.086*	-0.079					0.490	22.7
		94/95	0.103	-0.102					0.361	15.8
		95/96	0.000*						0.430	19.5
		96/97	-0.008*	-0.125	0.121				0.422	26.5
		97/98	0.109	-0.107					0.433	23.7
C	Shallow	92/93	-0.100		0.144				0.379	27.5
		93/94	-0.157		0.160				0.317	28.3
		95/96	-0.162		0.180				0.493	36.3
		96/97	-0.199		0.211				0.406	39.6
		97/98	-0.113		0.180	-0.062			0.609	52.4
		98/99	-0.180		0.214		0.539		0.819	42.4
	Deep	92/93	-0.158*			0.215			0.521	34.5
		95/96	-0.142		0.163		-0.193	-0.335		9.3
		96/97	-0.161		0.154		0.462		0.627	14.1
		97/98	-0.180		0.180				0.517	29.9
		98/99	-0.295		0.360				0.225	25.9

i) None of the variables for the data set of the season 1998/1999 in Zone A are significant.
ii) The symbol * means that the variable is not significant for the model (the t-value is in the interval from -2.15 to 2.15).

In addition, further investigation involving consideration of the data during the reds period was undertaken in order to compare the goodness-of-fit between models for the whole period and those for the reds period. Stronger relationships were found for some models of the reds phase using the same processes mentioned before. For example, the SCA output of an appropriate transfer function model of the shallow data set for the reds phase of the season 1997/1998 in Zone B is given as follows.

Table 5. 13: Appropriate transfer function model of the shallow data set for the reds phase of the season 1997/1998 in Zone B.

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN    1  THRU  135

 NONLINEAR ESTIMATION TERMINATED DUE TO:
 RELATIVE CHANGE IN (OBJECTIVE FUNCTION)**0.5 LESS THAN 0.1000D-02

 SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BS1

 ----------------------------------------------------------------------
 VARIABLE    TYPE OF    ORIGINAL     DIFFERENCING
             VARIABLE   OR CENTERED

 B9798SH     RANDOM     ORIGINAL     NONE

 B9798SW     RANDOM     ORIGINAL     NONE
 ----------------------------------------------------------------------

  PARAMETER    VARIABLE  NUM./  FACTOR  ORDER   CONS-       VALUE       STD      T
    LABEL        NAME    DENOM.                 TRAINT                  ERROR   VALUE

   1  CONST              CNST     1       0      NONE      -.0596      .0427   -1.39
   2    V0     B9798SW   NUM.     1       0      NONE      -.0617      .0250   -2.47
   3    V1     B9798SW   NUM.     1       1      NONE       .1107      .0250    4.42
   4   PHI     B9798SH   D-AR     1       1      NONE       .5625      .0675    8.33

 TOTAL SUM OF SQUARES . . . . . . . .  0.422916E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .           135
 RESIDUAL SUM OF SQUARES. . . . . . .  0.184501E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .           133
 R-SQUARE . . . . . . . . . . . . . .         0.557
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.138723E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.117781E+00
```

For this data set, the model for the reds period has one more explanatory variable, X_t, compared with the model for the full fishing season. Nevertheless, this variable is less significant than the variable X_{t-1}, which also exists in the model for the full fishing season, and the coefficient values in both models are similar. The model for the reds phase in this case has a stronger relationship than that for the full fishing season with the R^2 value increasing from 37.4% to 55.7% and the MSE value decreasing from 0.025 to 0.014. However, it was found after considering all red phase data sets that there are no consistent patterns. Stronger relationships for the reds phase did not appear in all models. Some of these models had the similar goodness-of-fit to those for the full fishing season, and some of these models appeared to have weaker relationships.

CHAPTER 6: *DISCUSSION and CONCLUSION*

This chapter provides a summary of the study presented in this thesis. Section 6.1 reviews the results outlined in the previous chapters, such as those for the effects of lunar cycle, swell, and water temperature on catch rates. The different time series models used for the relationships will be compared and discussed in section 6.2. Next, section 6.3 outlines the future research directions. Finally, the conclusion for the thesis is given in section 6.4.

6.1 Results of the Impact on Catch Rates

In this study, the effects of three environmental factors (i.e. lunar cycle, swell, and temperature) on the daily catch rates were examined. Section 6.1.1 outlines the results from the influence of lunar cycle while section 6.1.2 summarizes those for the impact of swell on catch rates. The results corresponding to the effect of sea water temperature on catch rates are summarised in section 6.1.3.

6.1.1 Results for Lunar Cycle

The investigation undertaken in chapter 4 indicates that lunar cycle has an impact on the daily catch rates for legal sized and undersized lobsters. The results also illustrate that lunar cycle has an influence on the setose catch rates in Zone C, but there is no evidence for such an effect on the catch rates in the other two zones. However, the results for Zone C might not be reliable since only three setose data sets were used for the investigation. In addition, the cycles of the legal sized lobsters in shallow water appear to show the clearest patterns for all three zones compared with those of the legal sized lobsters in deep water, undersized lobsters, and setose lobsters.

The results for Zone A do not show as clear a pattern as those in Zone B and Zone C. Although most of the minimum values from the cycles in Zone A for legal sized and undersized lobsters appeared during the full moon phase, the cyclical pattern was not strong. These unclear results might be the result of the time period used for examination of this zone because Zone A has a shorter fishing season than the other two zones. Data from only three and a half months of fishing were available for Zone A while seven and a half months of fishing were investigated for Zone B and Zone C. Therefore, the results for Zone A are not as reliable.

Unlike the results for Zone A, the results from Zone B and Zone C give clearer and stronger cycles with the minima corresponding to the full moon. For these two zones, the fishing season was separated into two different parts, the early season or the whites period and the late season or the reds period. The results for the period of whites and those for the period of reds display different cyclical patterns. There are no clear patterns related to moon phases for whites even though some cycles had the minimum values during the full moon phase. On the other hand, the cycles for the period of reds, like those for the full fishing season, show a strong cyclical pattern with the minima during the full moon period. The reds period (1^{st} February to the 30^{th} June) is twice as long as that of the whites (15^{th} November to the 31^{st} January), so the outcomes for the reds period show characteristics similar to the outcomes for the full fishing season.

Overall, cycles for the daily catch rates of all categories in all zones have a similar pattern. They are low during the full moon phase, increasing during the last quarter phase, high during the new moon phase, and decreasing during the first quarter phase. The cycles with the full fishing season in all zones and those with the reds period in Zone B and Zone C have the same pattern with the addition of the minimum values during the full moon period. Furthermore, the cycles for whites are more varied but still remain the pattern of the cycles for the catch rates.

The percentage below and above the average detrended catch rate for the minimum and maximum indices respectively during the full moon and new moon phases for each considered data set was calculated in order to indicate the effect of lunar cycle. A mean of the minimum or maximum values during the full moon or new moon period for all seasons was computed and compared with a mean of the 30 indices for all seasons in each category and each zone. Table 6.1 displays the percentages for the classical decomposition method in each data set following the periods of the catch.

Table 6. 1: Percentages below and above the average detrended catch rates corresponding to the minimum and maximum indices respectively during the full moon and new moon phases for all considered series.

Category	Zone, & Period	Full Moon	New Moon
Shallow	Zone A	– 20.93	11.43
	Zone B Full	– 27.79	16.28
	White	– 31.03	7.15
	Red	– 36.97	21.28
	Zone C Full	– 34.70	17.37
	White	– 53.45	29.10
	Red	– 35.48	22.43
Deep	Zone A	– 40.68	15.41
	Zone B Full	– 34.38	14.87
	White	– 76.95	44.55
	Red	– 36.48	15.22
	Zone C Full	– 36.35	14.53
	White	– 58.45	50.78
	Red	– 40.10	24.30
Undersize	Zone A	– 29.23	12.01
	Zone B Full	– 26.29	14.21
	White	– 37.67	22.48
	Red	– 29.22	16.22
	Zone C Full	– 32.61	18.90
	White	– 63.95	64.58
	Red	– 31.89	17.78
Setose	Zone C Full	– 64.89	32.47
	White	-	-
	Red	– 67.93	34.36

i) - The values were unavailable for calculation due to the problem of method used.
ii) The "–" sign in front of all numbers indicates the percentages below the averages.

The percentages below the averages for legal sized and undersized series during the period of reds and the full fishing season lie between 26 and 40 percent while those above the averages range from 14 to 24 percent. It is clear that the percentages for the reds period and the full fishing season in each data set are similar while the percentage for the whites period are quite different. The range for the percentages below the averages of legal sized reds is 35-40%, and that above the averages of legal sized reds is 15-24%. In addition, the ranges are 29-32% and 16-18% for the percentages below and above the averages of undersized reds. The ranges for whites are more varied and higher than those for reds. Furthermore, the percentages for the setose data sets show greater variation than those for the legal sized and undersized series. This may be the result of the limited number of data used for the examination.

6.1.2 Results for Swell

The cross correlation functions between the adjusted catch rates and the swell show significant correlation of the swell with the legal sized catch rates. Most of the results for the shallow data sets in Zone B and C and deep data sets in Zone A, B, and C have positively significant cross correlations at lag -1. Thus, on the day before the catch, there is evidence that the swell has an effect on legal sized catch rates for shallow water in Zone B and C and on legal sized catch rates for deep water in all three zones. It is possible that the positive impact of the swell on the legal sized catch rates might be because legal sized lobsters are more active and catchable when the swell disturbs the bottom and increases food availability as well as provides greater protection for them.

However, the significant cross correlations for the shallow data sets are higher than those for the deep data sets. The correlations of the shallow series are approximately 60% higher. This fact indicates that the impact of the swell on the catch rates in shallow water is stronger than that on the catch rates in deep water. On the other hand, the cross correlation functions of the adjusted catch rates with the swell do not indicate any clear evidence of a relationship between the catch rates and the swell in any other categories such as undersized and setose lobsters.

Cross correlation functions were also computed to find the correlation between catch rates of whites as well as catch rates of reds and swell. Unlike the cross correlation functions for the period of whites, the results for the period of reds were similar to those for the full fishing season. Most of the significant lags for the reds period were the same as those for the whole fishing season in each data set. Conversely, there were few significantly strong cross correlations between catch rates of whites and swell at some specific lags.

To ensure that the overall correlation was not the result of correlation within each data set, the cross correlation functions between the residuals of the catch rates and the residuals of the swell after removing the AR or MA trend from both series were calculated. The outcomes of this confirmed the results of the cross correlation functions of adjusted catch rates with swell. Furthermore, most of the cross correlation functions between the purely random series for the undersized data sets and the purely random series for the swell in zone B displayed negatively significant values at lag 0. As a result, swell should have an influence on the catch rates of undersized lobsters in Zone B at the day of the catch. One of the reasons for the negative effect of the swell on the undersized catch rates in Zone B might be the habitat of undersized lobsters. Undersized lobsters usually stay in the inshore reefs. When the swell occurs, fishers would tend not to fish close to these areas. Therefore, the catch rates of undersized lobsters in Zone B may decrease.

6.1.3 Results for Water Temperature

Unlike the results for the lunar cycle and the swell, there is no evidence for an impact of sea water temperature on daily catch rates. Although the cross correlation functions of the original catch rate and the trend with the temperature at Rat Island in Zone A showed a pattern with both the catch rate or the trend and the temperature reducing with time, further investigation indicates that the reason for the correlations here might be the downward trend in the two series. As a result, the effect of the water temperature from summer to winter is confounded by the decline in abundance due to the effect of fishing. In addition, there were some problems with the different patterns of the cross correlations occurring in the results for temperature at different areas of the same zone in the same season. Therefore, the temperature may only have an impact on the catch rate in an area surrounding a particular site but not for the whole zone.

6.2 Modelling Results

In this thesis, the relationship between adjusted catch rates and swell were fitted with suitable time series models. The shallow series in Zone B and C, the deep series in all three fishing zones, and the undersized series in Zone B for the full fishing season were first investigated by using ARIMA models to ascertain the identities of all series for proposed models. The results from ARIMA models indicated that the AR(1) process was appropriate for almost all of the series for adjusted catch rates in Zone B and C and swell in all zones. Consequently, the current value, X_t, of these data sets can be described by the past value, X_{t-1}. Unlike the combination of adjusted catch rates in Zone B and C and swell, the adjusted catch rates for deep water in Zone A can be fitted by the white noise or the MA(1) process. Therefore, the current value for adjusted catch rates is purely random or linearly combined between the white noise at the present and the past lags (Z_t and Z_{t-1}).

From the results given in section 4.3, it is clear that swell has a positive impact on catch rates at lag –1. In addition, some cross correlations are strongly significant at lag 0 and lag –2. Thus, three different lags of the swell were considered for explaining the catch rates. It was initially assumed for time series models in this study that the response variable, Y_t, stands for the adjusted catch rates while the three explanatory variables, X_t, X_{t-1}, and X_{t-2}, represent the swell at the present time and the swell on the day and two days before the catch.

Next, regression models were used to fit the relationships between the adjusted catch rates and the swell. The fitted models, after finalizing display, showed that only the explanatory variable X_{t-1} had a strong effect on the response variable Y_t for the legal sized data sets. Only the explanatory variable X_t was strongly related to the response variable Y_t for the undersized data sets in Zone B. This is probably because the variables X_t, X_{t-1}, and X_{t-2} are high correlated, so some problems of singularity of the variables may occur. However, the regression models given at this state were not really appropriate for the data since the residuals from the fitted models were autocorrelated. Therefore, more suitable models were required for explaining the relationship between the adjusted catch rates and the swell.

Since the preliminary analysis indicated that most of the adjusted catch rates for each data set could be fitted by the AR(1) process, the past values of the adjusted catch rates at lag –1 or Y_{t-1} should be included as an explanatory variable in order to improve the models. Only the explanatory variable X_{t-1} remained in the models for legal sized catch rates while only the explanatory variable X_t remained in the models for undersized catch rates in Zone B. Therefore, the new regression models for the legal sized data sets were models with the response variable Y_t and the two explanatory variables X_{t-1} and Y_{t-1}. In addition, the response variable Y_t and the two explanatory variables X_t and Y_{t-1} could be used to create new regression models for undersized data sets in Zone B.

These new regression models improved the goodness-of-fit for the relationships between the catch rates and the swell. The R^2 values for the new models were higher than the R^2 values for the old ones, and almost all of the residuals for the new fitted models were purely random. Nevertheless, another kind of models like transfer function models was also considered in order to find a better fit for the relationships.

For the transfer function models, the output series and the input series were assumed to be the adjusted catch rates Y_t and the values of the swell X_t respectively. The results corresponded to the cross correlation functions between the catch rates and the swell given in section 4.3. The fitted transfer function models demonstrated that the swell at the day before the catch had the positive impact on the legal sized catch rates in Zone A (in deep water only), in Zone B, and in Zone C. In addition, the swell at the day of the catch had a negative influence on undersized catch rates in Zone B. As a result, the catch rates on the day before appear to be the most considerable explanatory variable in the variation of the current catch rates in Zone B and Zone C although this is not the case for Zone A.

In comparison, all of the fitted models show the same relationships between catch rates and swell. The models indicate that the legal sized catch rates have a positive relationship with the swell on the day before the catch, and the undersized catch rates in Zone B have a negative relationship with the swell on the day of the catch. The transfer function models appear to be the most appropriate models for the data sets used in this study. The statistical values such as R^2 and MSE confirm this fact.

Overall, the R^2 values for the transfer function models are higher than those for the regression models in both cases (Case 1: regression models with the predictor variables X_t, X_{t-1}, and X_{t-2}, Case 2: regression models with the predictor variables X_{t-1} and Y_{t-1} for legal sized data or those with the predictor variables X_t and Y_{t-1} for undersized data in Zone B). The MSE values for the transfer function models are slightly lower than those for the regression models. Table 6.2 shows the R^2 and MSE values for all fitted models.

Table 6. 2: R^2 values for all models fitted to the relationships between the catch rates and the swell.

Zone	Depth	Season	Regression: Case 1		Regression: Case 2		Transfer Function	
			R-square	MSE	R-square	MSE	R-square	MSE
A	Deep	92/93	9.2	0.108	27.2	0.087	41.5	0.067
		93/94	7.3	0.064	7.3	0.065	26.2	0.050
		95/96	22.5	0.015	22.7	0.015	22.7	0.014
		96/97	9.1	0.064	21.1	0.056	18.9	0.055
		97/98	------------	------------	13.2	0.044	27.5	0.035
		98/99	------------	------------	------------	------------	------------	------------
B	Shallow	93/94	5.7	0.045	25.3	0.036	27.0	0.034
		94/95	16.3	0.034	43.2	0.023	45.5	0.022
		95/96	7.5	0.029	37.3	0.020	43.2	0.017
		96/97	17.9	0.041	43.3	0.028	48.9	0.025
		97/98	2.7	0.040	36.1	0.026	37.4	0.025
		98/99	9.2	0.036	50.0	0.020	51.9	0.019
	Deep	93/94	9.7	0.286	20.0	0.255	19.6	0.252
		94/95	------------	------------	28.0	0.180	29.7	0.173
		95/96	4.2	0.239	11.8	0.221	14.3	0.212
		96/97	------------	------------	17.7	0.238	18.3	0.232
		97/98	------------	------------	34.4	0.111	36.4	0.106
		98/99	4.1	0.253	12.9	0.231	16.4	0.218
	Undersize	93/94	------------	------------	21.6	0.050	22.7	0.049
		94/95	4.7	0.031	13.5	0.029	15.8	0.027
		95/96	------------	------------	19.6	0.040	19.5	0.039
		96/97	------------	------------	18.6	0.036	26.5	0.032
		97/98	5.8	0.035	21.0	0.029	23.7	0.028
C	Shallow	92/93	7.0	0.045	25.1	0.036	27.5	0.035
		93/94	18.2	0.025	25.4	0.023	28.3	0.021
		95/96	13.0	0.042	31.3	0.033	36.3	0.030
		96/97	22.9	0.039	35.3	0.033	39.6	0.030
		97/98	17.4	0.027	41.8	0.019	52.4	0.015
		98/99	27.5	0.023	33.9	0.021	42.4	0.018
	Deep	92/93	6.1	0.204	34.7	0.143	34.5	0.141
		95/96	------------	------------	------------	------------	9.3	0.108
		96/97	3.1	0.133	8.9	0.126	14.1	0.117
		97/98	2.7	0.160	28.8	0.117	29.9	0.114
		98/99	21.5	0.102	23.1	0.100	25.9	0.095

Case 1: Regression models with the explanatory variables X_t, X_{t-1}, and X_{t-2}.
Case 2: Regression models with the explanatory variables X_{t-1}, and Y_{t-1}.

Furthermore, graphs for the fitted values of different models were compared with the actual values. These are given in Appendix M. In general, the results verify that the transfer function models are the most suitable models for demonstrating the relationships. The regression models in the first case have a poor fit compared with the regression models in the second case and compared with the transfer function models. Although the fitted values of the regression models in the second case and those of the transfer function models are quite similar in some data sets, the transfer function models are invariably a better fit. The fitted values of these models are then closer to the actual values in almost all data sets. For example, the graph of fitted values from three different models for the relationship between the adjusted catch rates and the swell in the shallow data set of Zone C for the fishing season 1998/1999 is shown in Figure 6.1. In addition, the fitted transfer function models are not more complicated than the regression models with the predictor variables X_{t-1} and Y_{t-1} for legal sized data or with the predictor variables X_t and Y_{t-1} for undersized data in Zone B. Most of the transfer function models do not have more parameters involved in the models.

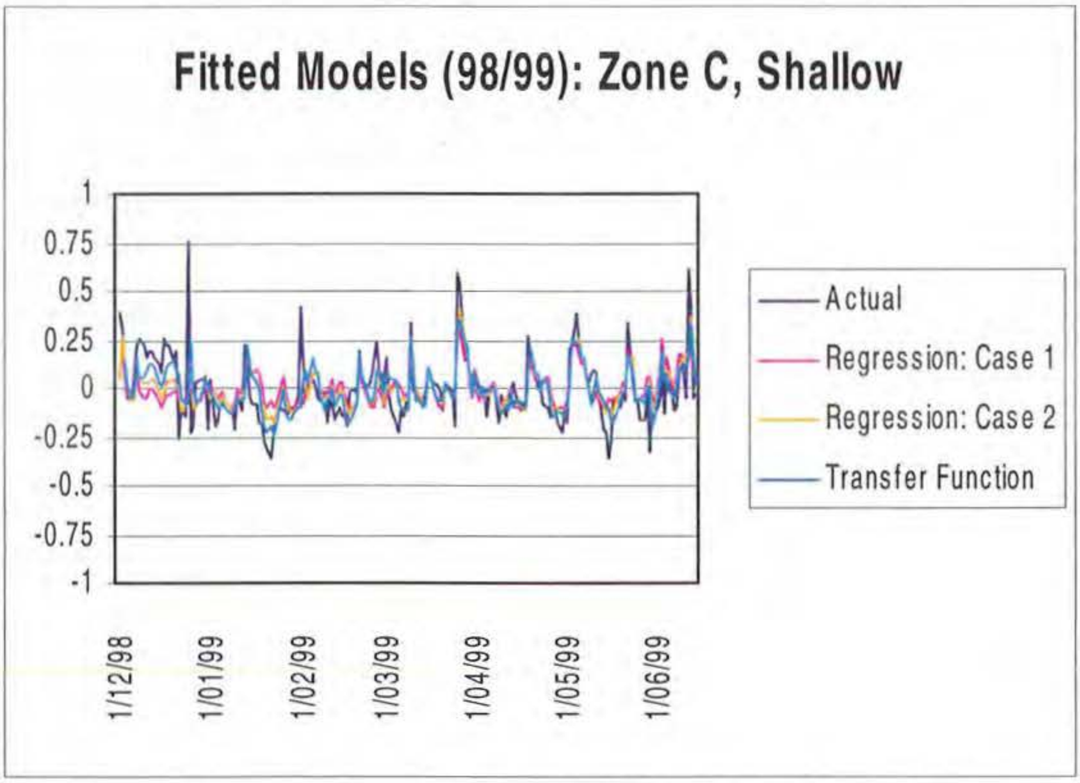


Figure 6. 1: Fitted values from three different models compared with the actual values of the adjusted catch rates (the shallow data set in Zone C for the fishing season 1998/1999).

6.3 Future Research Directions

In this thesis, two different depths, depth of 0-20 fathoms and depth of > 20 fathoms, were taken into account for the examination of the legal sized catch rates. The depth of 0-10 fathoms and the depth of 20-30 fathoms were used for the undersized and setose lobsters respectively. Nevertheless, a study focussing on the impact of the five different depths (i.e. 0-10, 10-20, 20-30, 30-40 and > 40 fathoms) for each lobster category may provide more consistent results. The investigation undertaken of the five different depths may show more detail about how environmental factors influence the catch rate of lobsters in each category. However, some depth categories could be combined to reduce the level of missing data.

Unlike previous localised studies, there was no clear evidence for an impact of water temperature on the catch rates in this research. The daily variation in the temperature was not sufficient to detect changes in the catch rates. In addition, this was probably the result of available temperature data. For this study, only three-year data from 1992 to 1994 were available. Moreover, the data were taken from particular sites and did not cover the whole zone. There is clear evidence that the water temperature can vary significantly within a particular zone. Thus, more consistent temperature data need to be gathered in order to get the better results.

Certain models were used to find the relationship between swell and catch rates. However, alternative models such as state space models, which include a number of powerful devices for modelling, for example, structural time series models and regression models with ARIMA disturbances, might also be applied. In addition, some more advanced models may be available for fitting the effects of the lunar cycle on the catch rates.

The model for the catch rates here is:

$$\text{Catch Rates} = \text{Trend} \times \text{Cycle} \times \text{Adjusted Catch Rates}$$

where the cyclical component is related to moon phases, and the adjusted catch rates correspond to the swell. Further research might consider other variables to provide a better explanation of the relationship. The impact of scenarios such as moon closures can be clearly identified. Using this model, the improved index of the western rock lobster abundance can be obtained to provide better management. These known facts are hopefully helpful for predicting the stock assessment of the fishery.

6.4 Conclusion

The aims of this research were to investigate the impact of lunar cycle, swell, and sea water temperature on catch rates of the Western rock lobster and to develop suitable models for resulting relationships in order to provide better insights for the stock recruitment. Data of seven fishing seasons ranging from 1992/1993 to 1998/1999 were considered. Some data sets were excluded due to the gaps of missing values in the series. Several time series methods such as moving averages and centred moving averages, cross correlations, classical decomposition, Holt-Winters method, ARIMA models, regression models, and transfer function models were used to provide the research results.

The results of the study show an impact for moon phases on the catch rates for legal sized and undersized lobsters in all three zones as well as for setose lobsters in Zone C. The full moon phase has a significant impact on catch rates with the minimum values when the full moon occurs. In general, the cycles of the catch rates increase during the last quarter phase, are high during the new moon phase, and decrease during the first quarter phase. The swell also has an effect on the catch rates for legal sized lobsters (except those for shallow water in Zone A) on the day before the catch. Besides, there is a relationship between the undersized catch rates in Zone B and the swell on the day of the catch. Different models were fitted to the relationships between the catch rates and the swell. The results indicate that transfer function models generally provide better results than regression models fitted to the data sets. Unlike lunar cycle and swell, water temperature does not seem to have any clear effect on catch rates.

In conclusion, these results will enhance the management of the Western rock lobster fishery by providing a better understanding of some environmental variables affecting catch rates of the western rock lobster at different times and different locations. The moon phases and the swell may need to be taken in consideration when models for an assessment of stock recruitment are undertaken. The results will be valuable in the better management of this important fishery.

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APPENDIX A: *Position of the temperature loggers*

Positions of the temperature loggers

Site	Latitude °S	Longitude °E
South Passage	26°08'	113°12'
Rat Island	28°42'	113°46'
Seven Mile Beach	29°10'	114°54'
Jurien Bay	30°19'	115°00'
Alkimos	31°38'	115°39'
Warnbro Sound	32°21'	115°41'
Cape Mentelle	33°57'	114°59'

(Source: Fisheries Research Report No. 111, 1999)

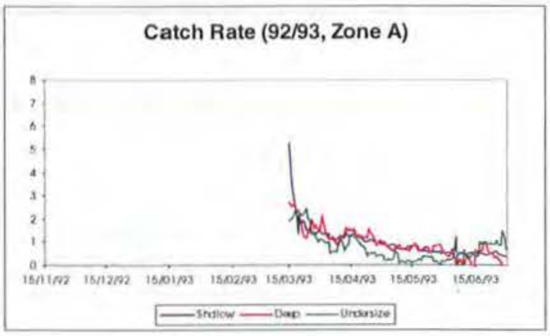
APPENDIX B: *Weekly Bump's data*

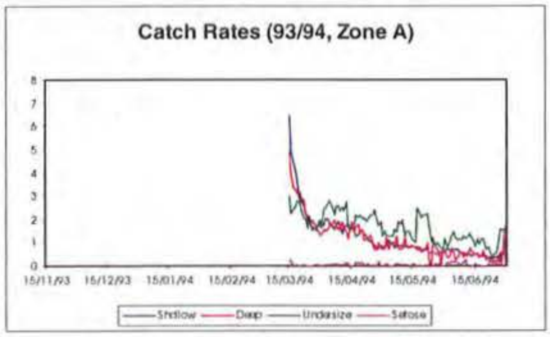
Weekly Bump's data

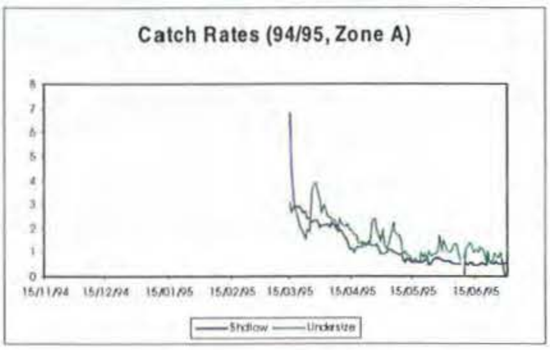
Week	Sales (Thousands)	Price per Gallon	Advertising Expense (Hundreds of Dollars)
1	10	1.30	9
2	6	2.00	7
3	5	1.70	5
4	12	1.50	14
5	10	1.60	15
6	15	1.20	12
7	5	1.60	6
8	12	1.40	10
9	17	1.00	15
10	20	1.10	21

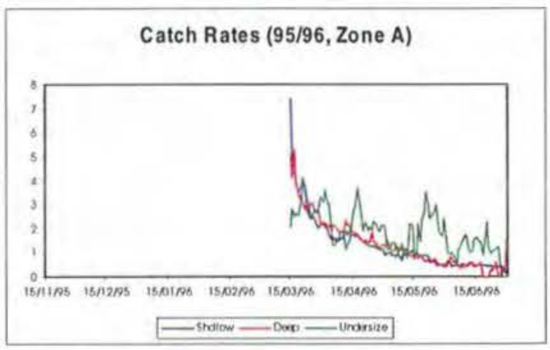
APPENDIX C: *Graphs of the catch rate data used in the thesis*

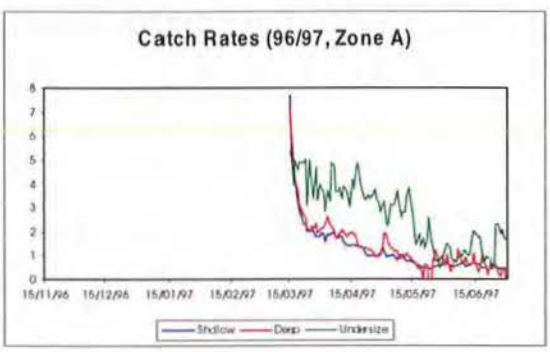
Time series plots of the daily catch rate data in Zone A

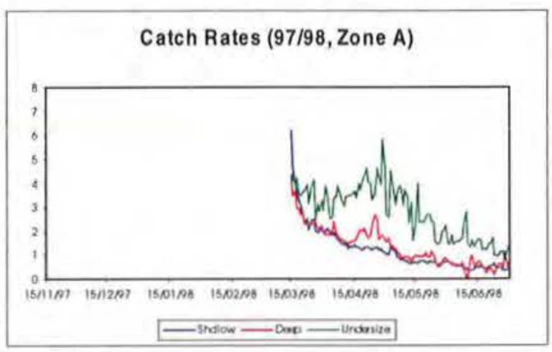


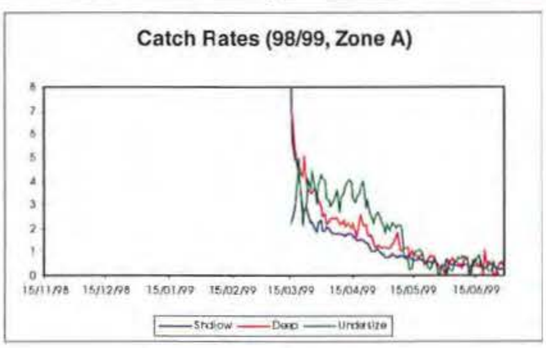




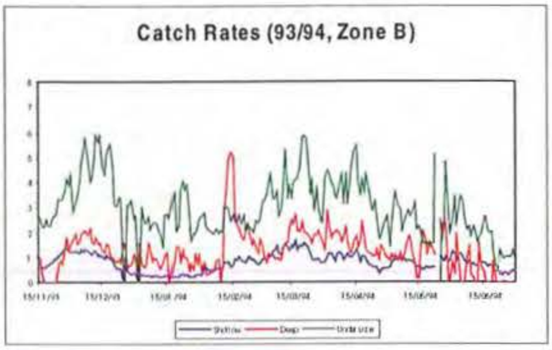


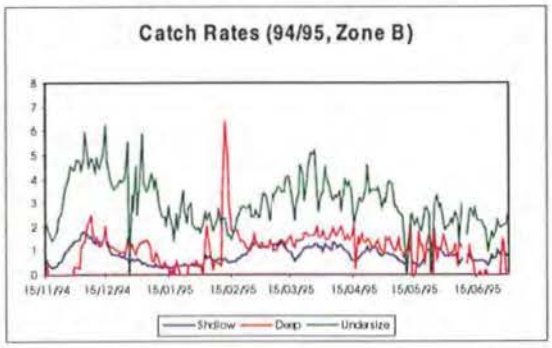


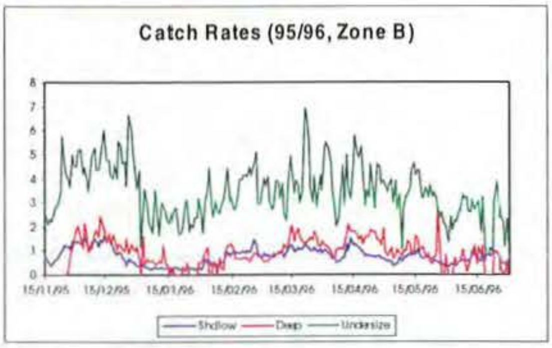


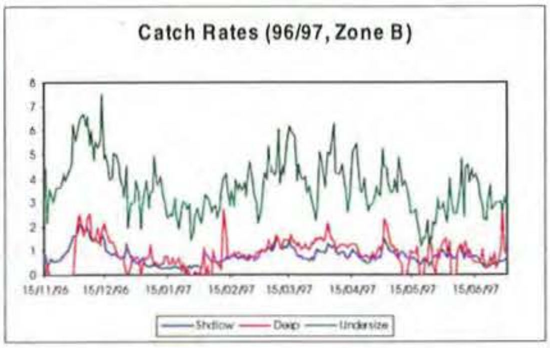


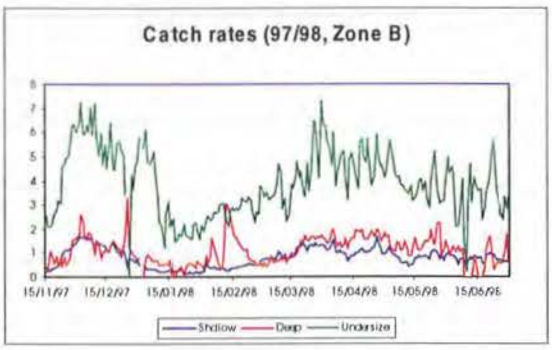
Time series plots of the daily catch rate data in Zone B

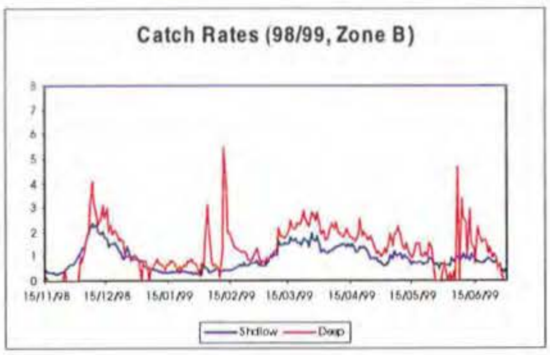




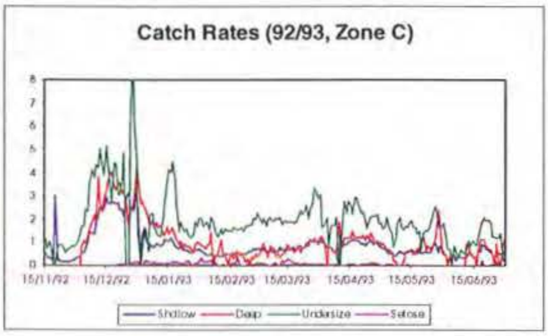


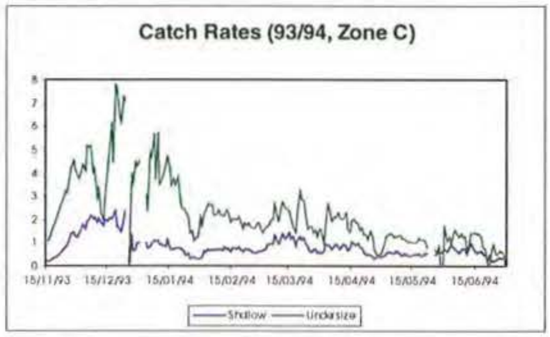


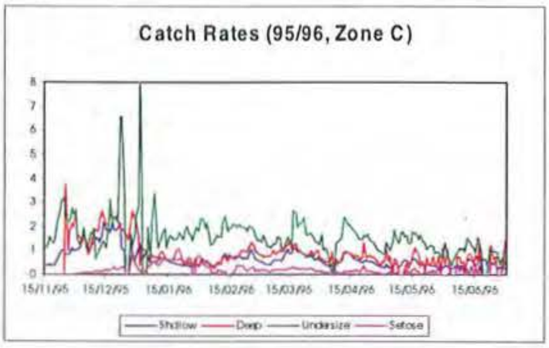


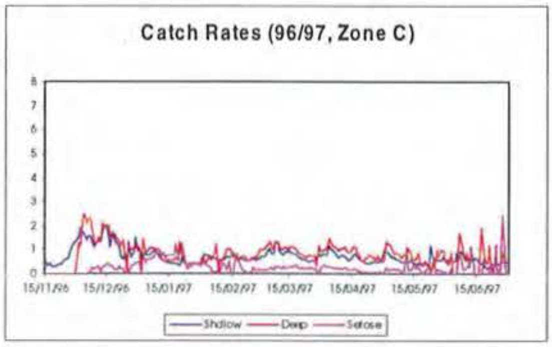


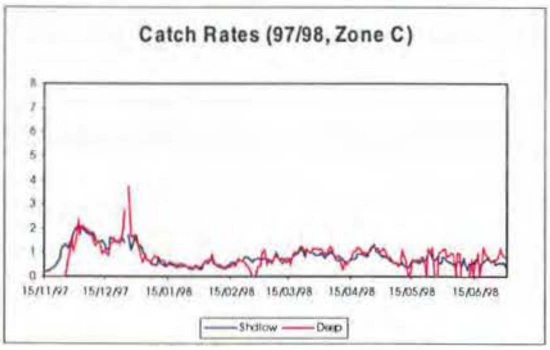
Time series plots of the daily catch rate data in Zone C

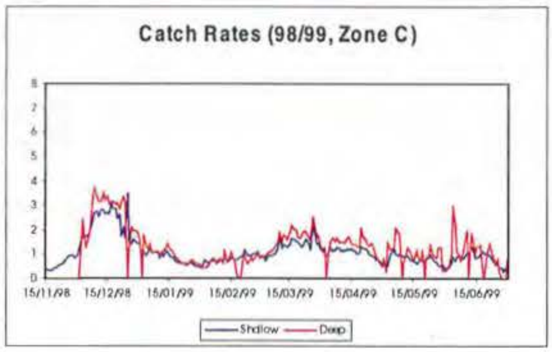






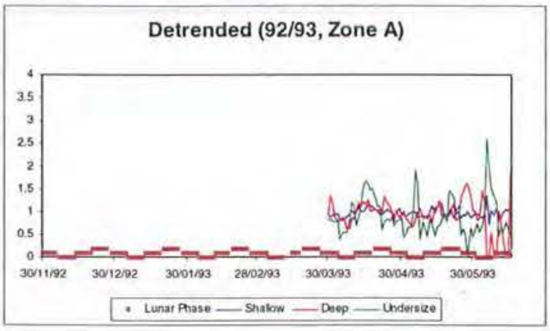


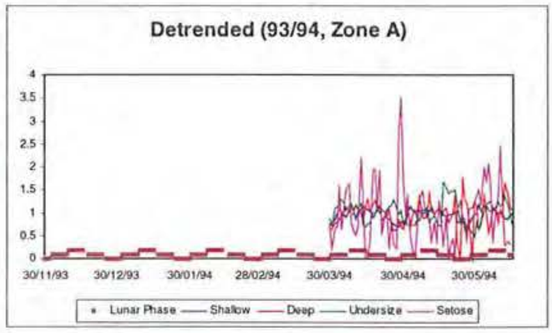


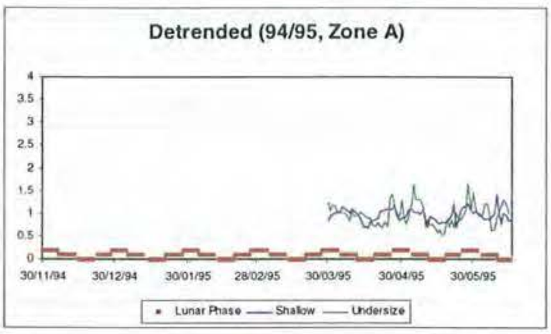


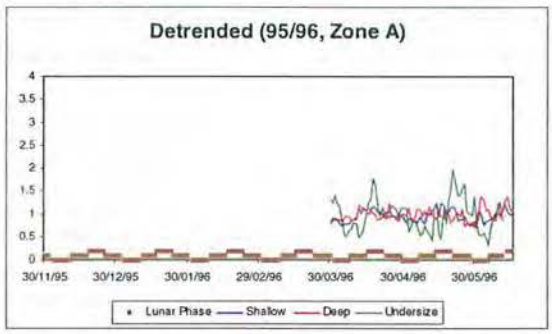
APPENDIX D: *Detrended catch rates compared with the lunar phase*

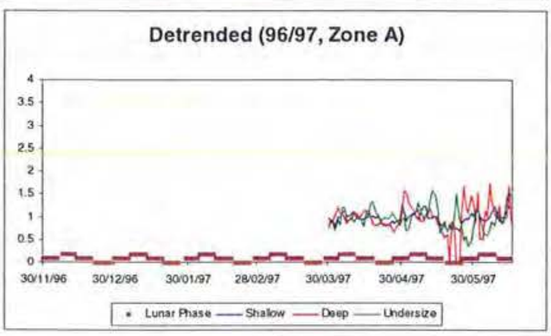
Time series plots of detrended catch rates in Zone A

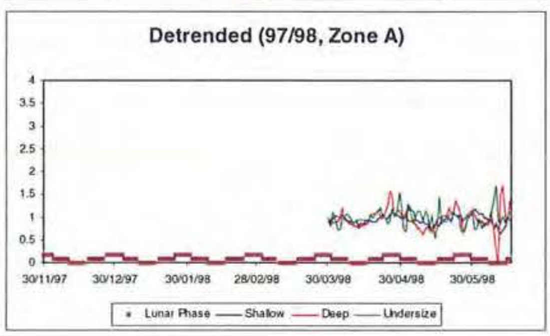


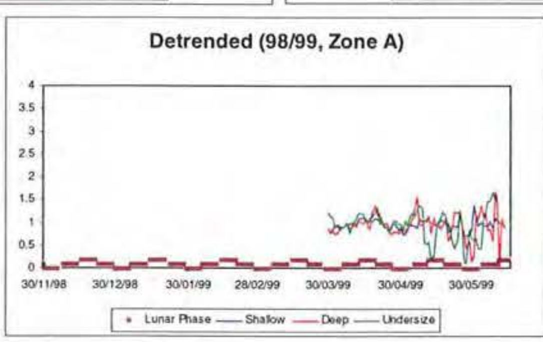




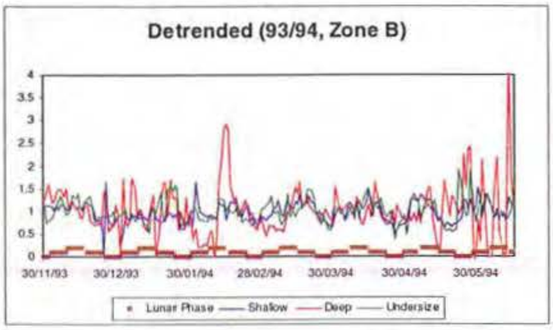


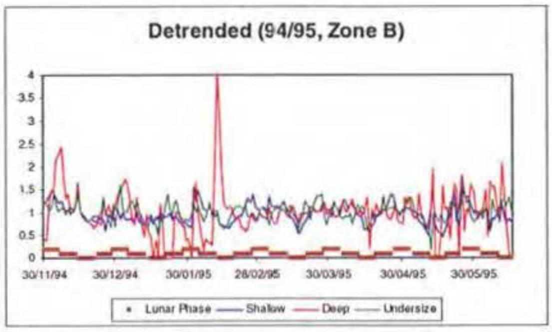


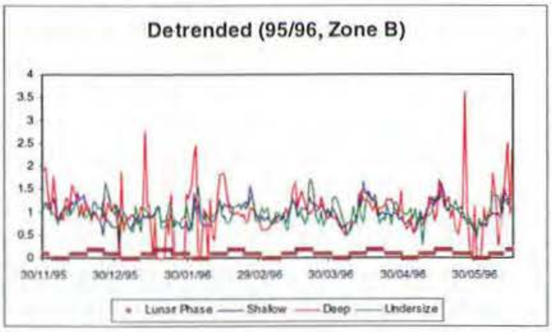


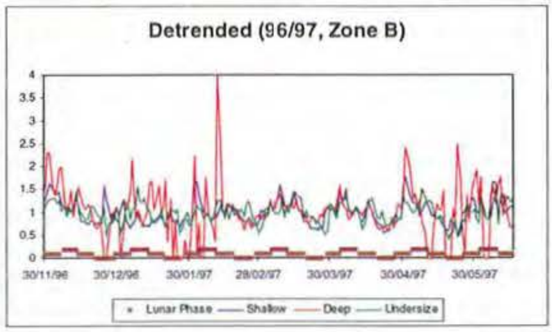


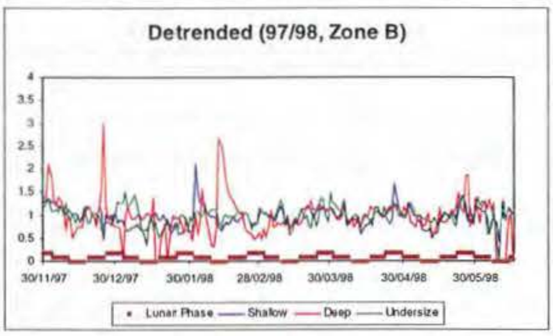
Time series plots of detrended catch rates in Zone B

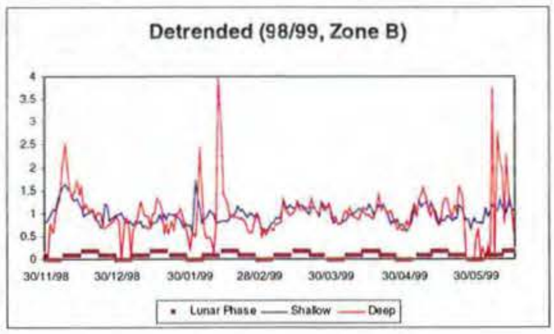




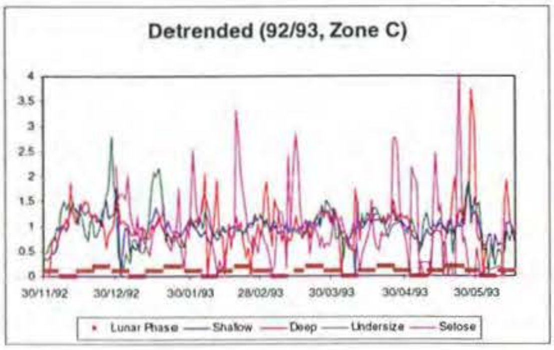


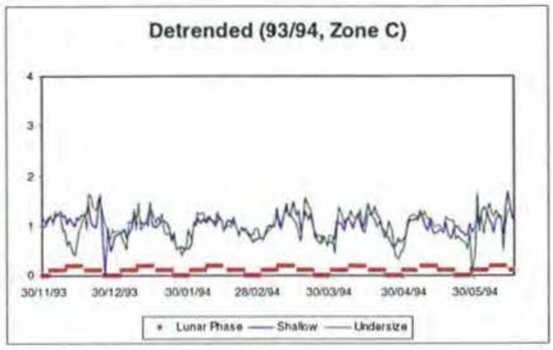


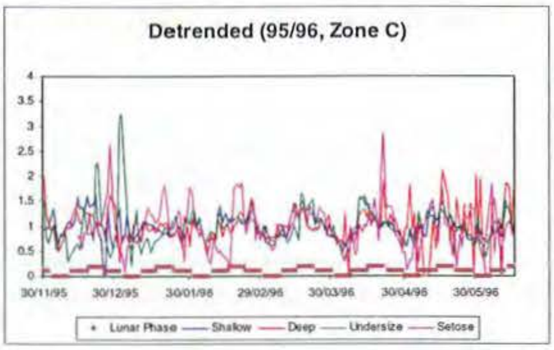


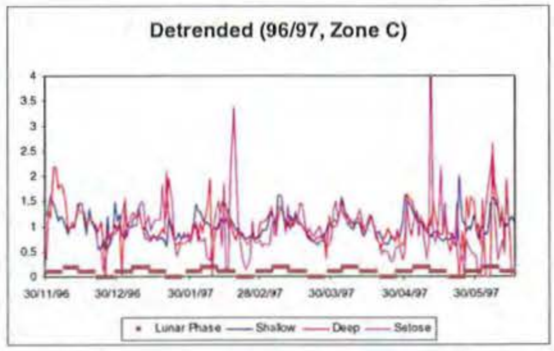


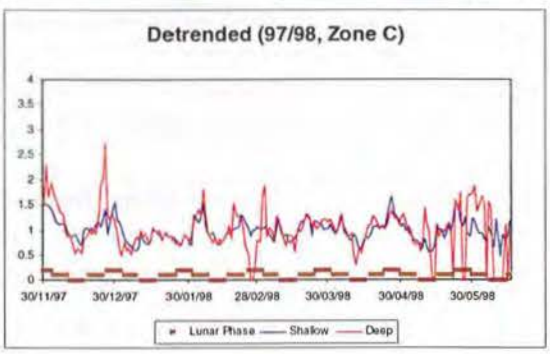
Time series plots of detrended catch rates in Zone C

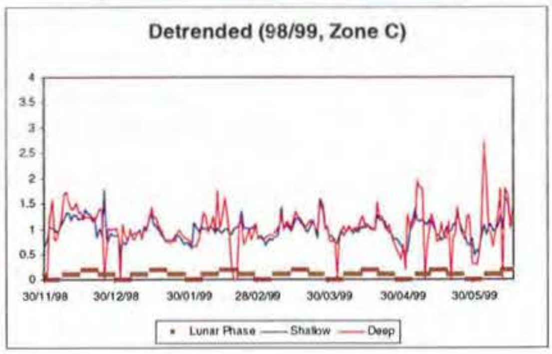






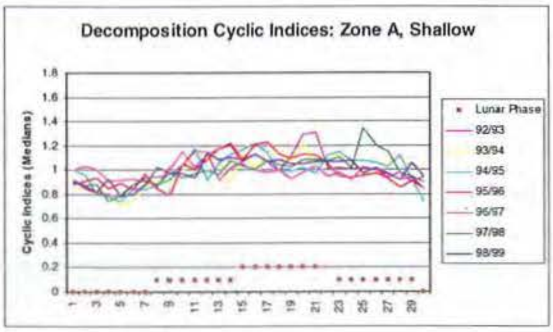


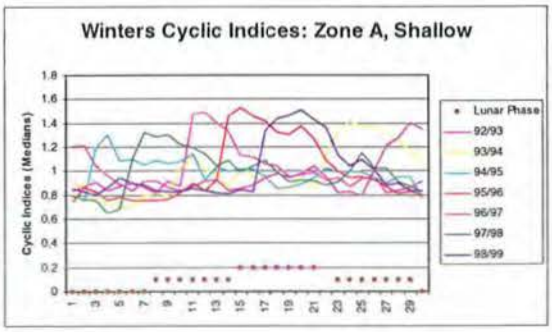


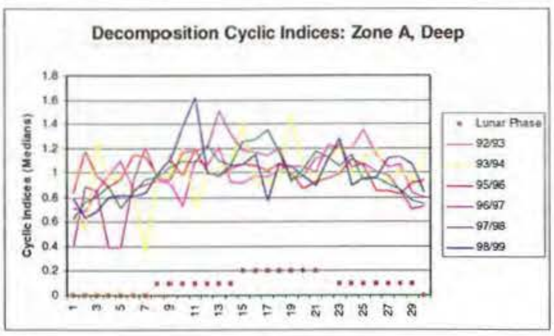


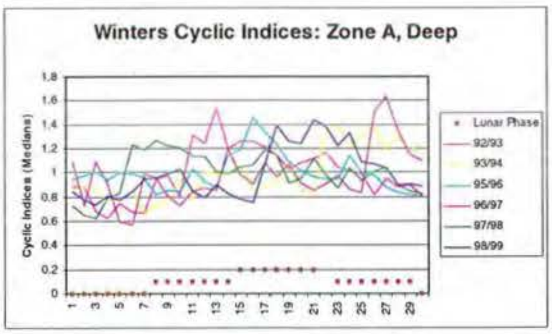
APPENDIX E: *Thirty cyclic indices compared with the lunar phase*

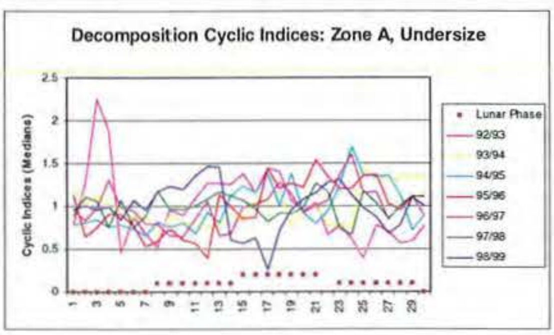
Time series plots of 30 cyclic indices derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone A used in this study

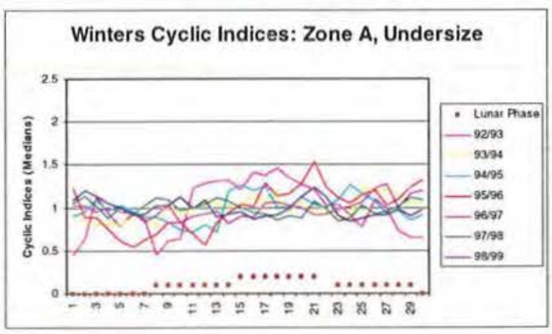


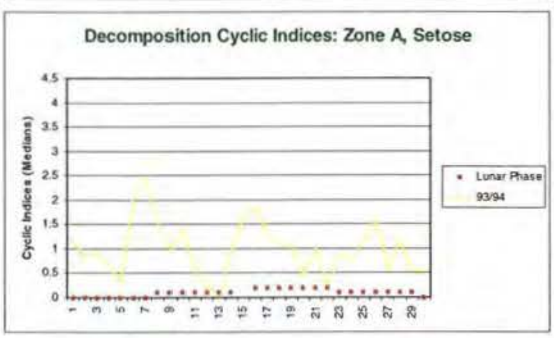


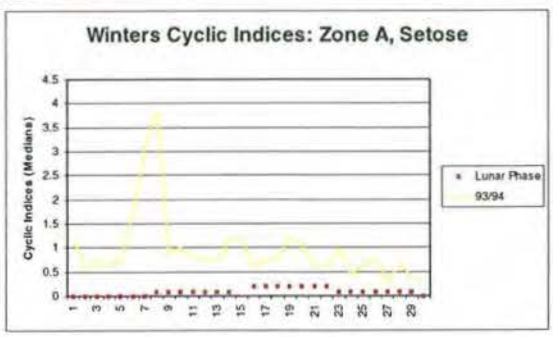




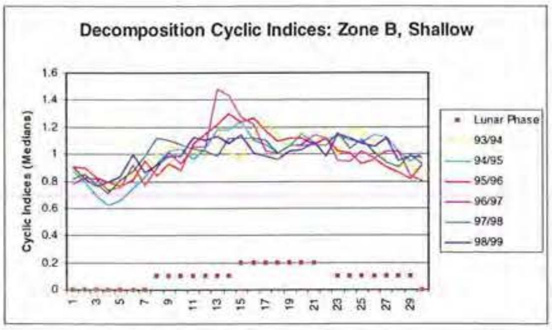


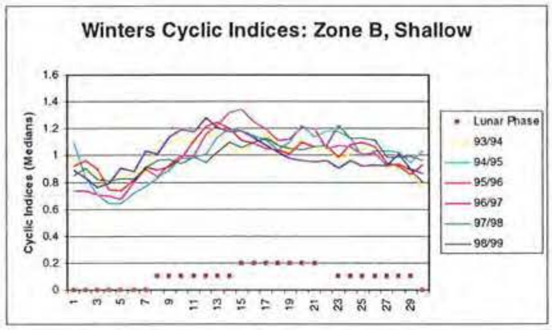


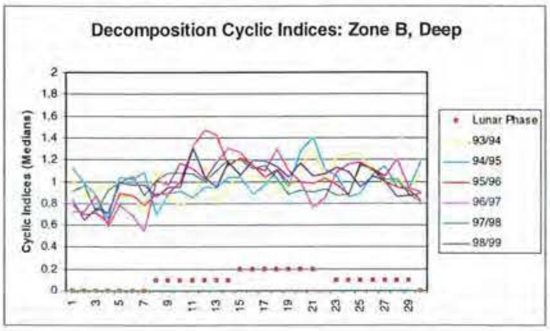


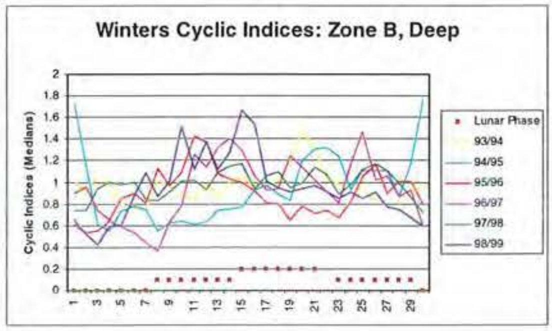


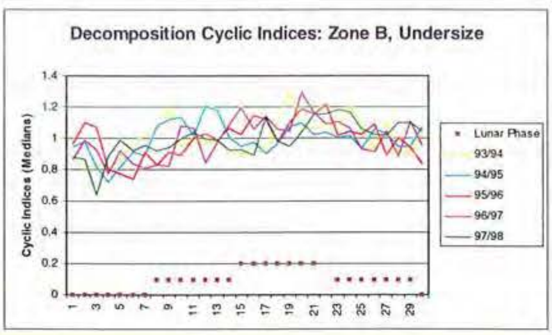
Time series plots of 30 cyclic indices derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone B used in this study

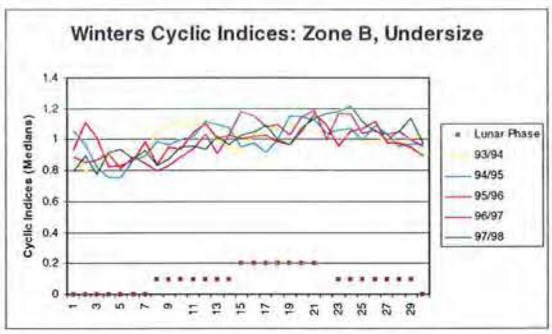




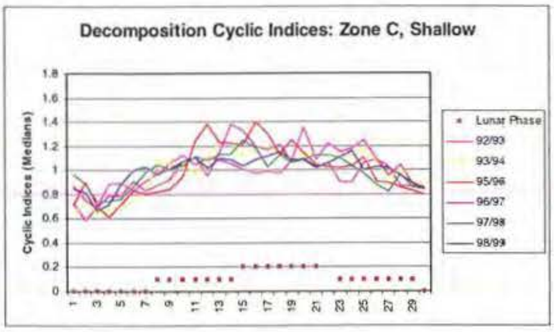


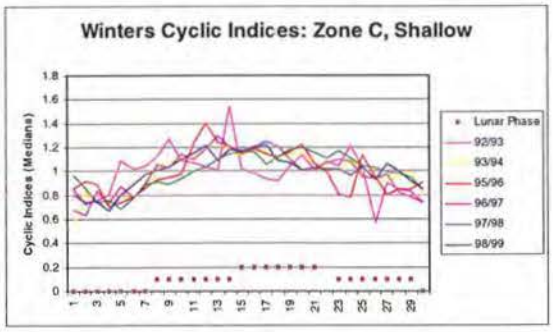


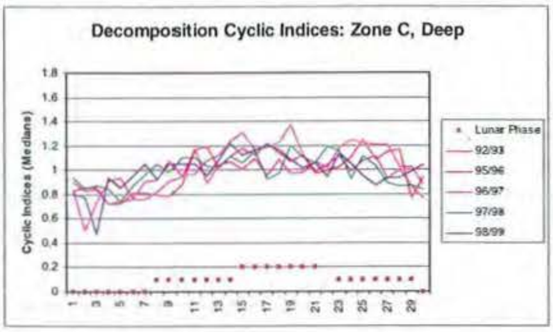


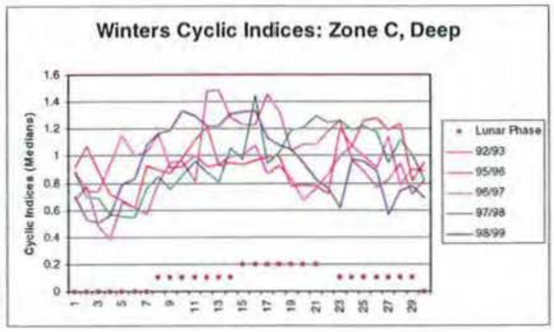


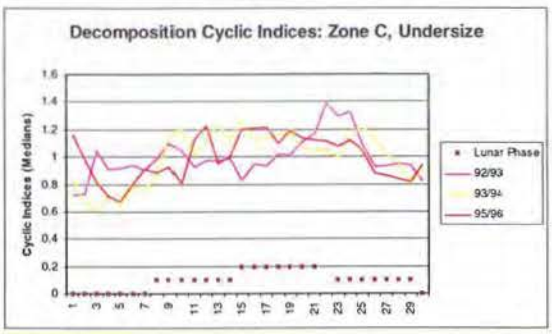
Time series plots of 30 cyclic indices derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone C used in this study

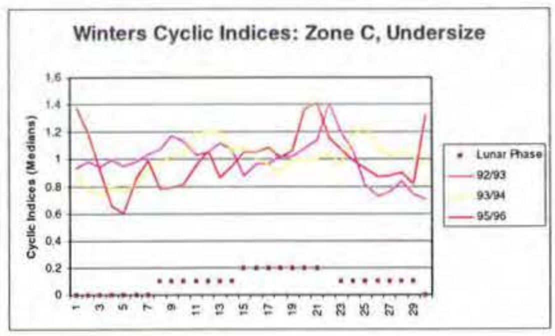


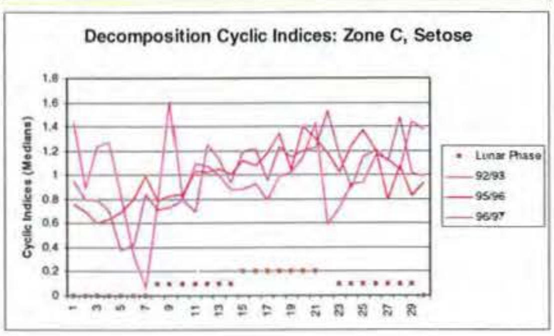


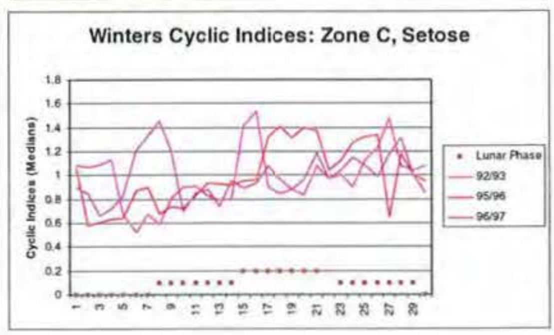




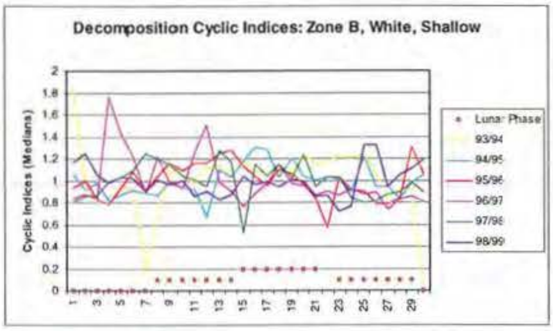


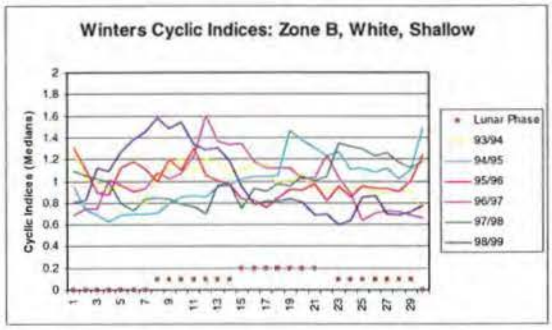


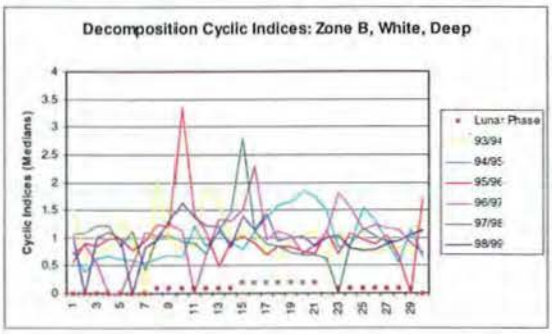


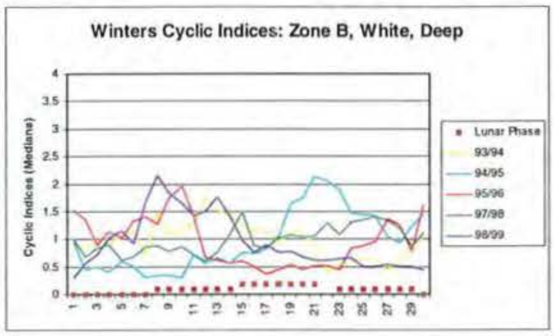


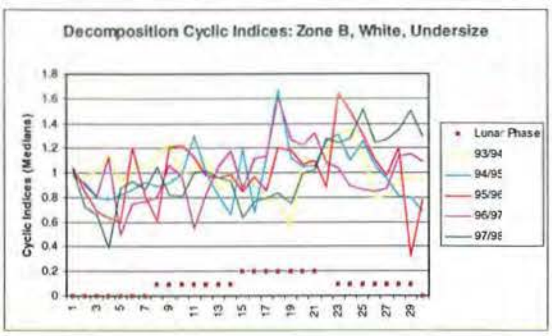
Time series plots of 30 cyclic indices during the period of whites derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone B used in this study

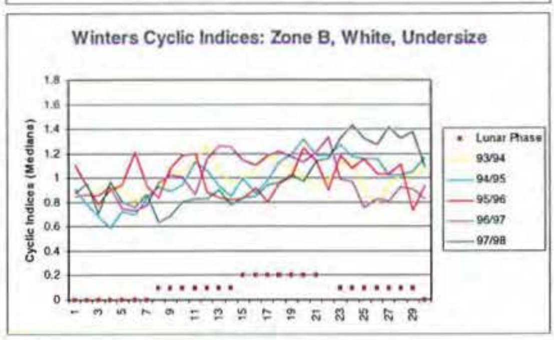




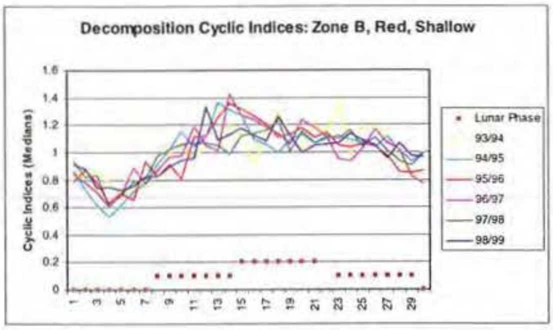


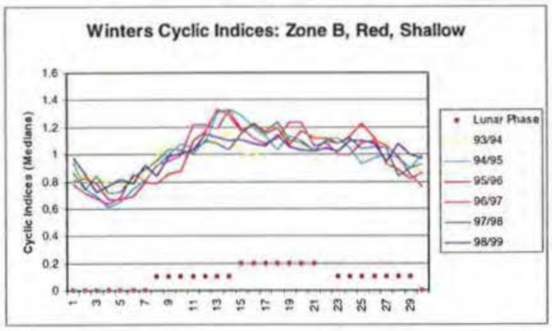


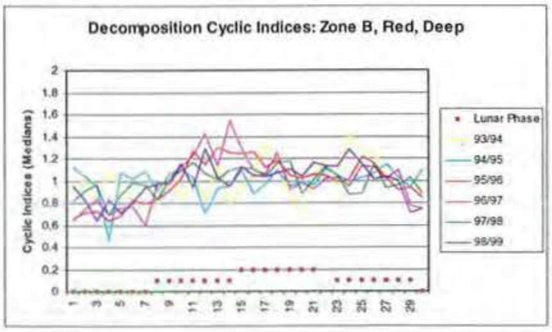


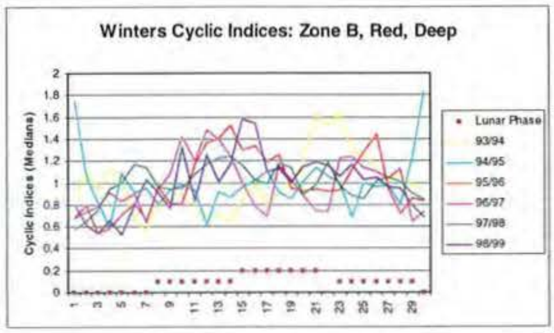


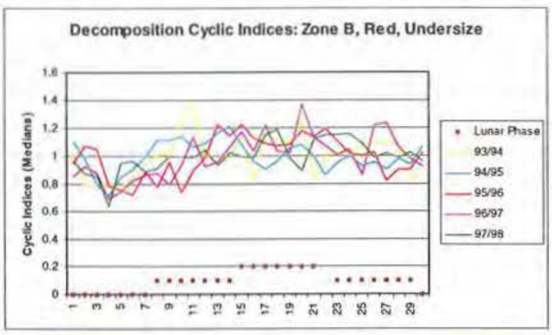
Time series plots of 30 cyclic indices during the period of reds derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone B used in this study

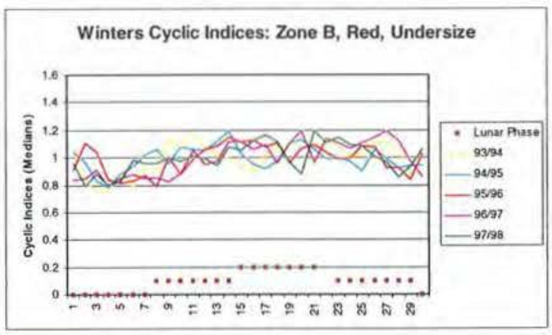




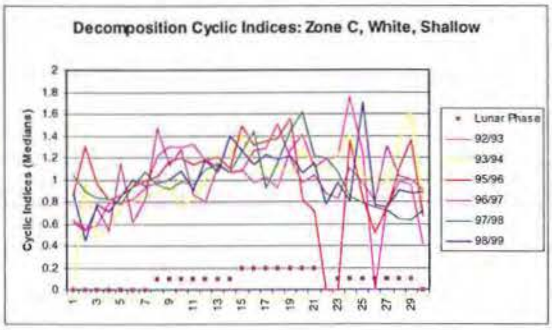


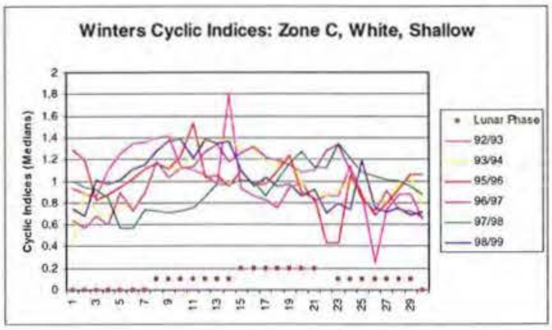


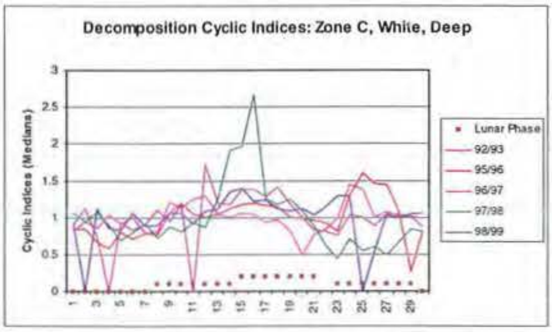


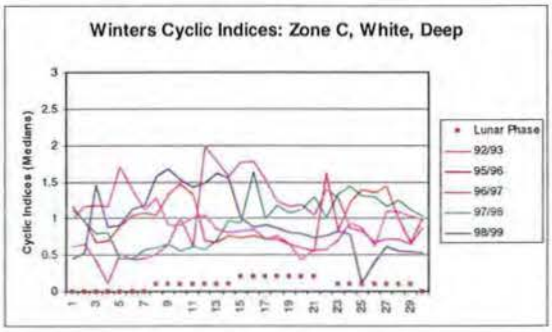


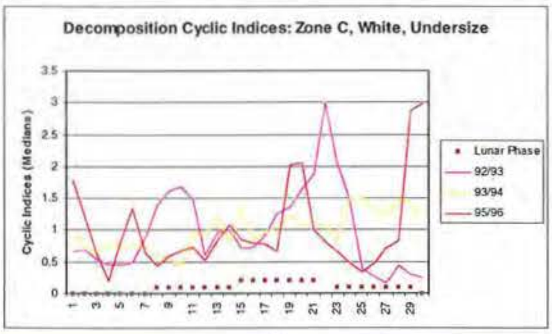
Time series plots of 30 cyclic indices during the period of whites derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone C used in this study

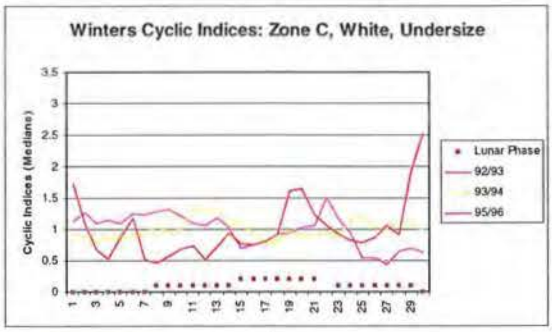


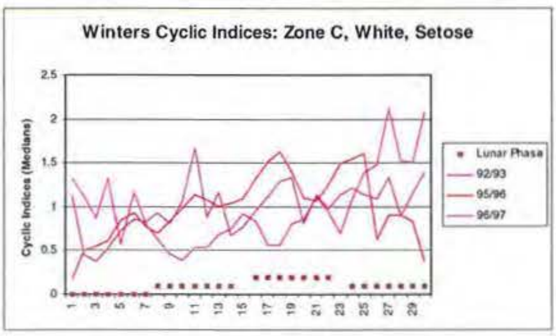




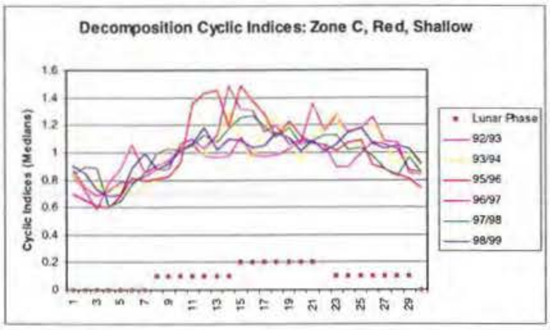


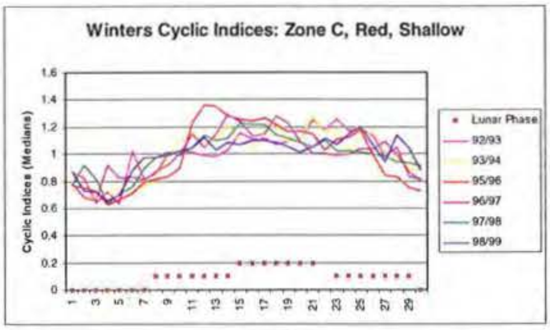


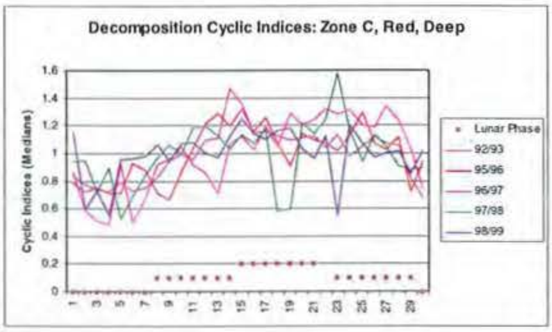


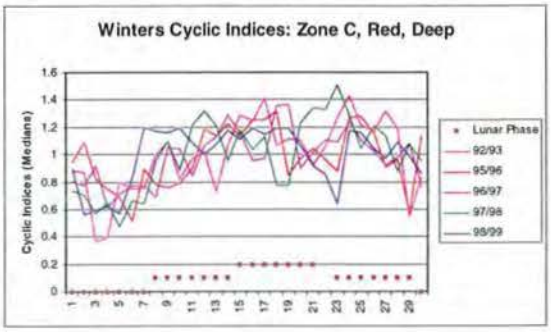


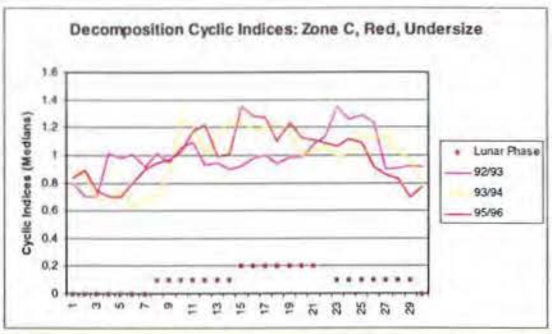
Time series plots of 30 cyclic indices during the period of reds derived from the decomposition and Holt-Winters methods compared with the lunar cycle for every data set of Zone C used in this study

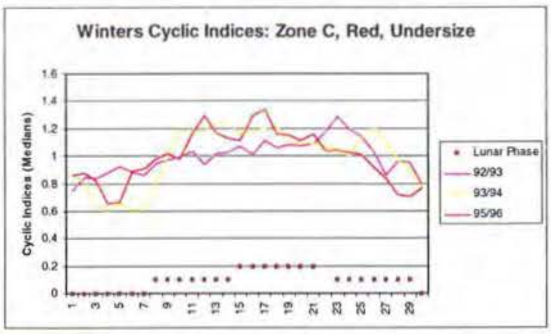


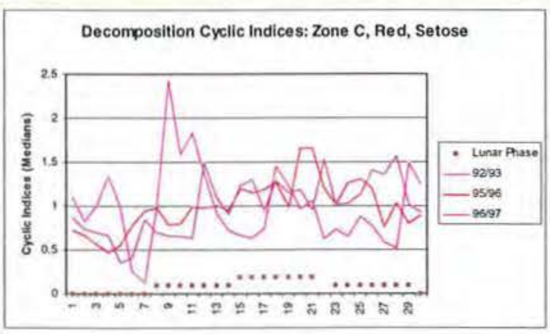


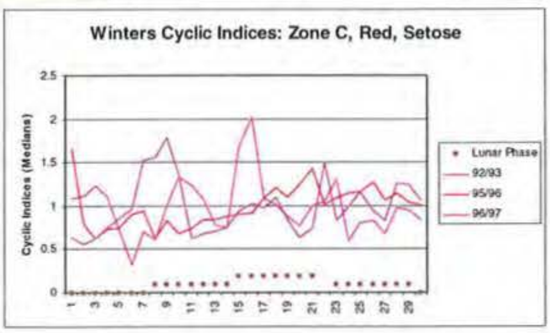






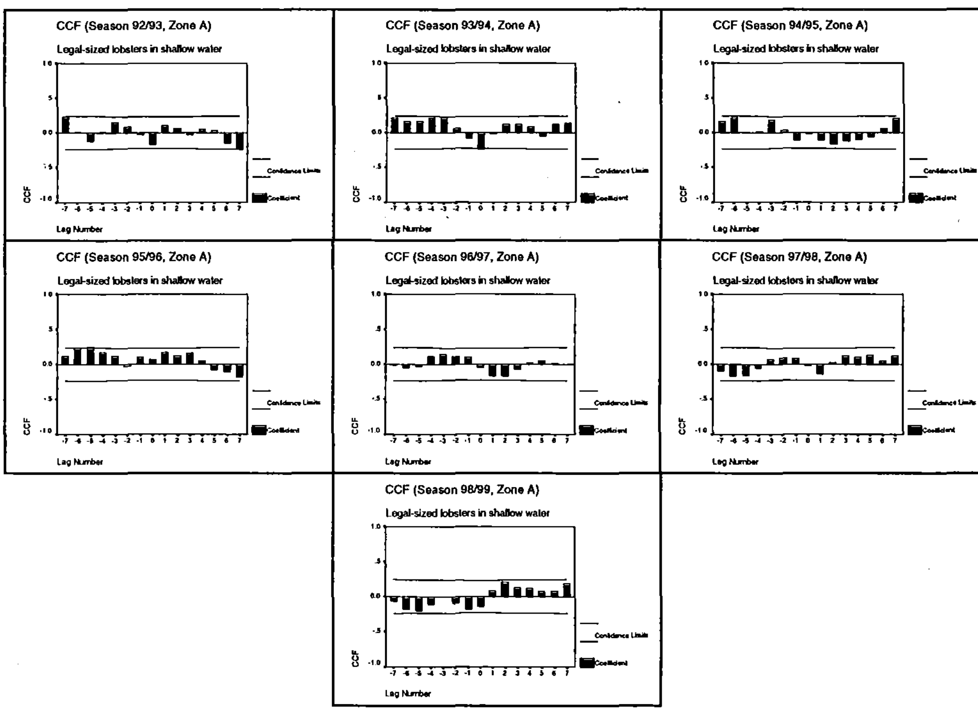




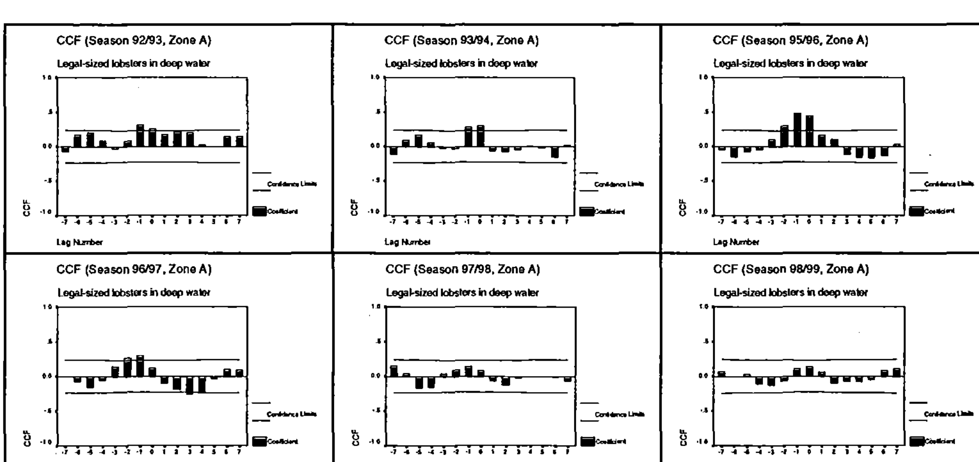


APPENDIX F: *Cross correlations of adjusted catch rates with swell*

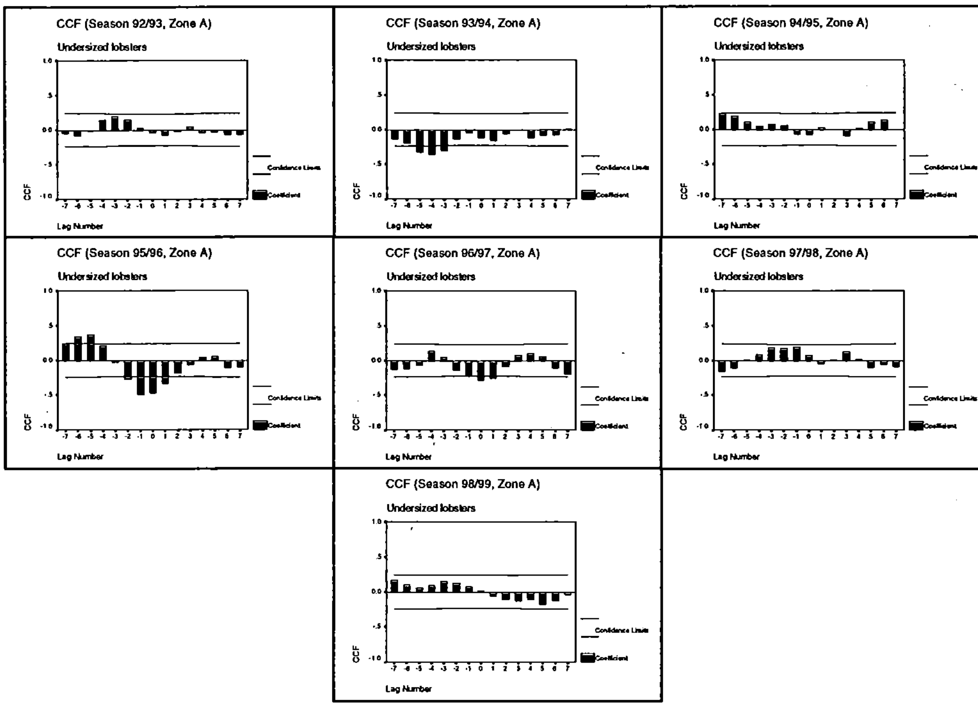
Cross correlations of adjusted catch rates of legal sized lobsters in shallow water, Zone A, with swell for every available season



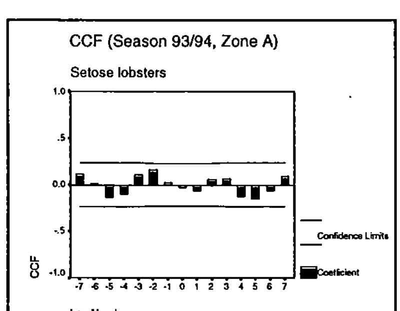
Cross correlations of adjusted catch rates of legal sized lobsters in deep water, Zone A, with swell for every available season



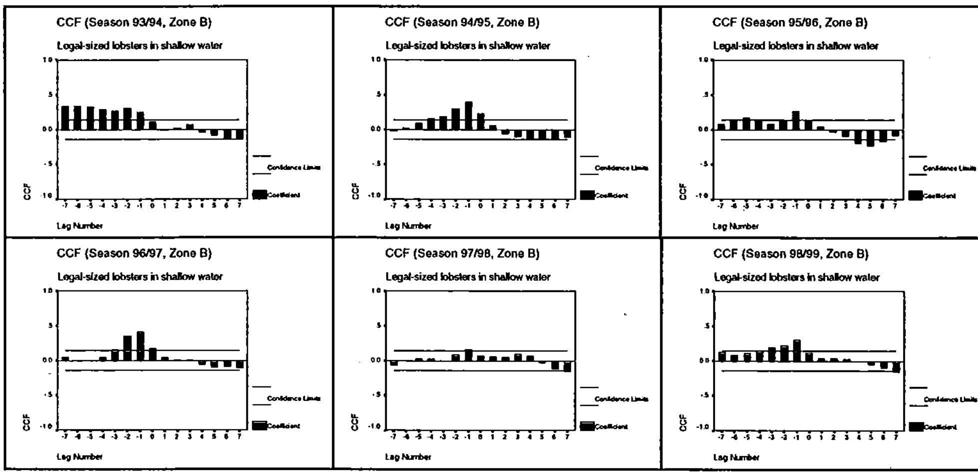
Cross correlations of adjusted catch rates of undersized lobsters in Zone A with swell for every available season

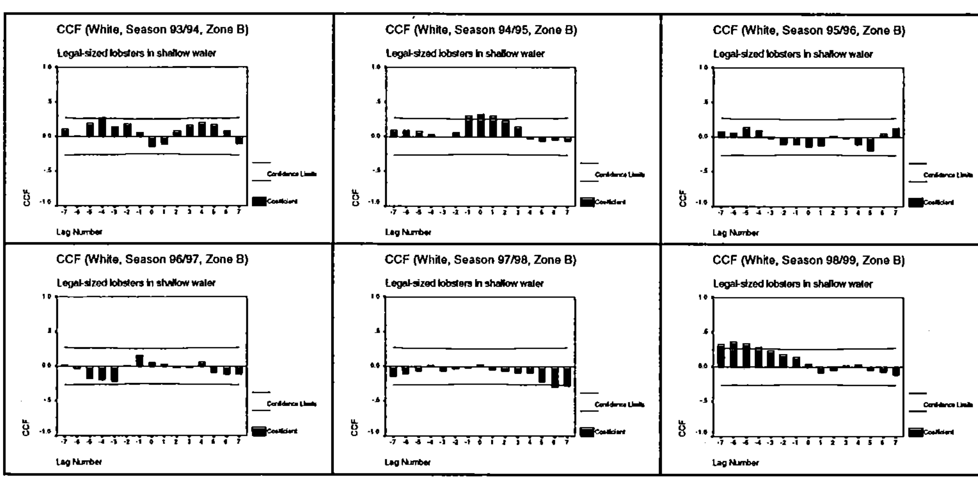


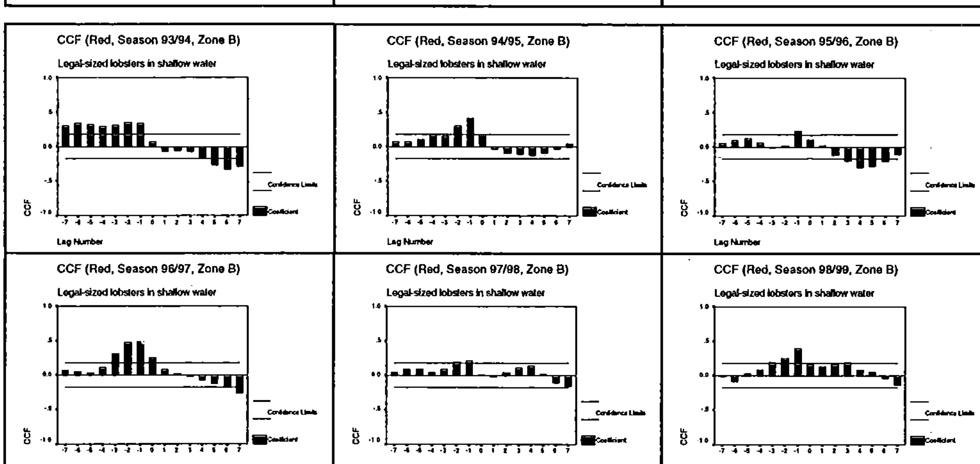
Cross correlations of adjusted catch rates of setose lobsters in Zone A with swell for the season 1993/1994



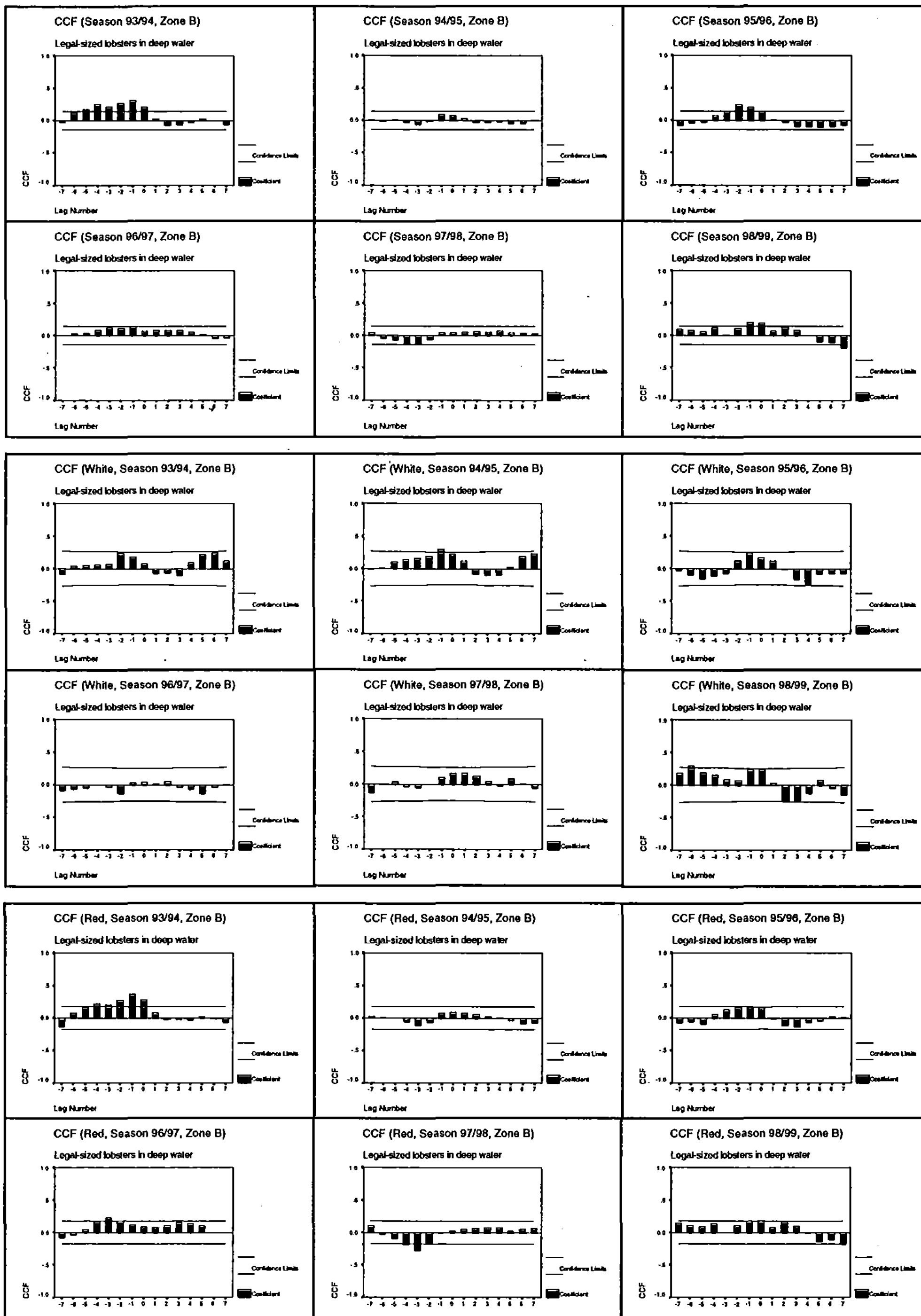
Cross correlations of adjusted catch rates of legal sized lobsters in shallow water in Zone B with swell for the whole period of every available season as well as the periods of whites and reds



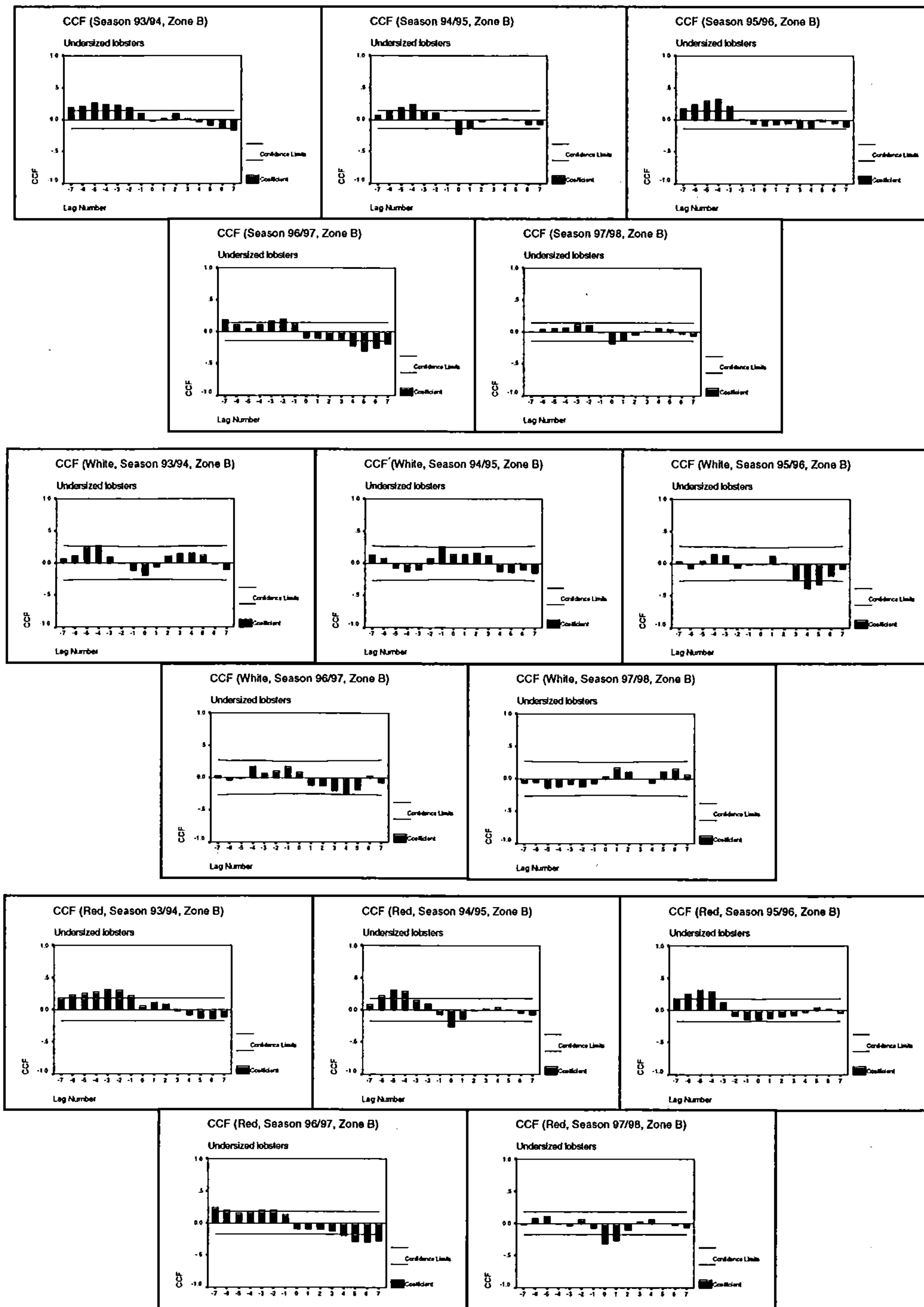




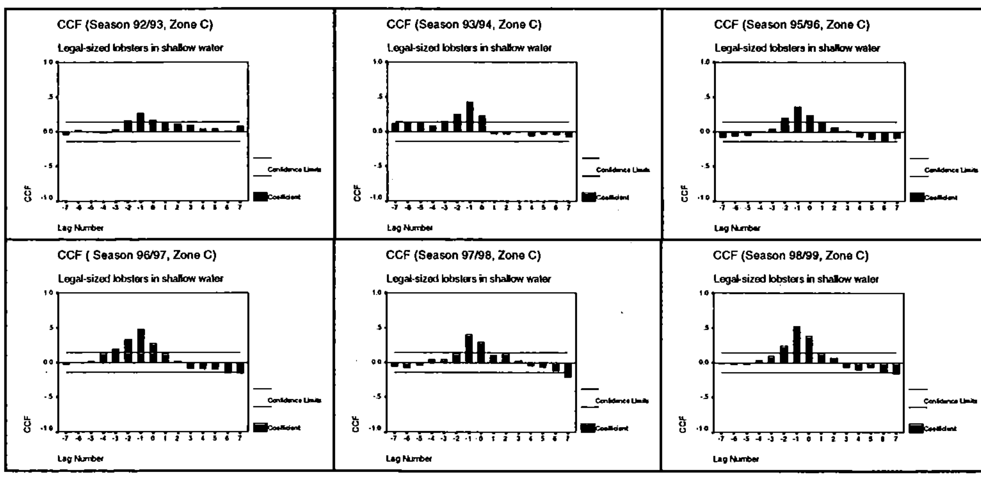
Cross correlations of adjusted catch rates of legal sized lobsters in deep water in Zone B with swell for the whole period of every available season as well as the periods of whites and reds

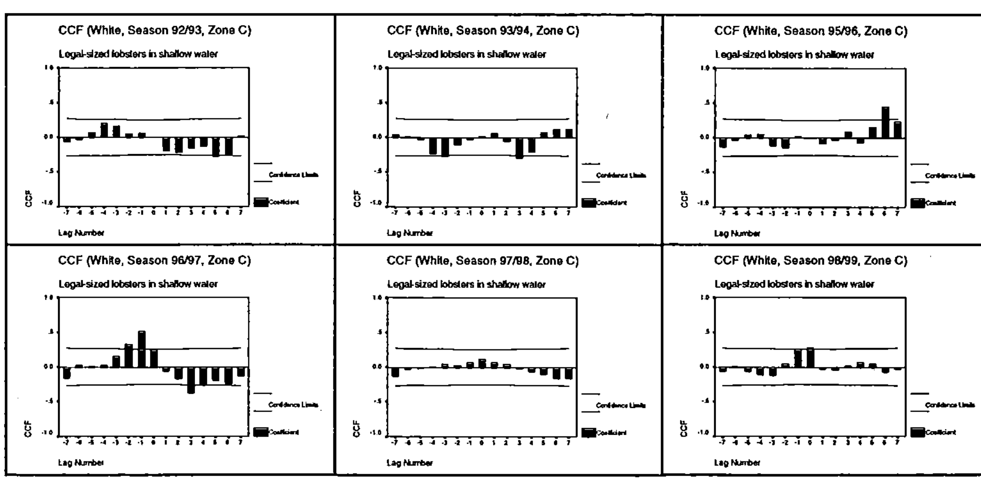


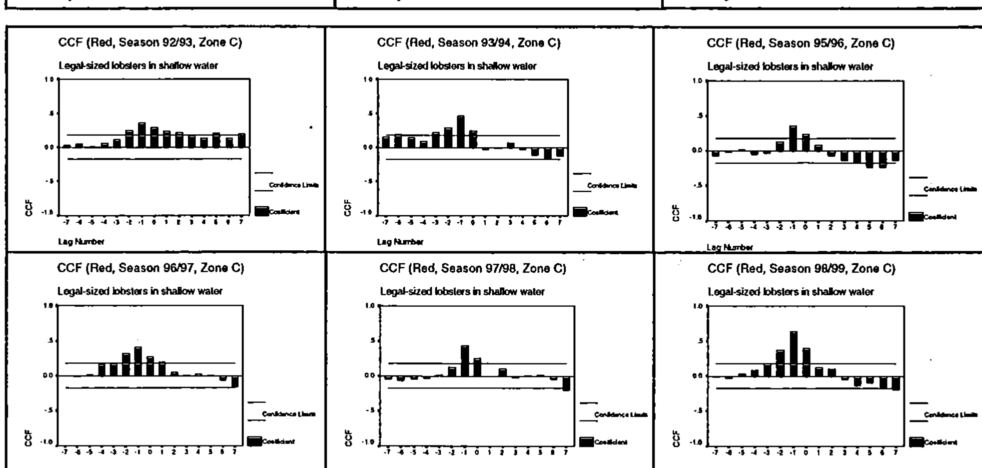
Cross correlations of adjusted catch rates of undersized lobsters in Zone B with swell for the whole period of every available season as well as the periods of whites and reds



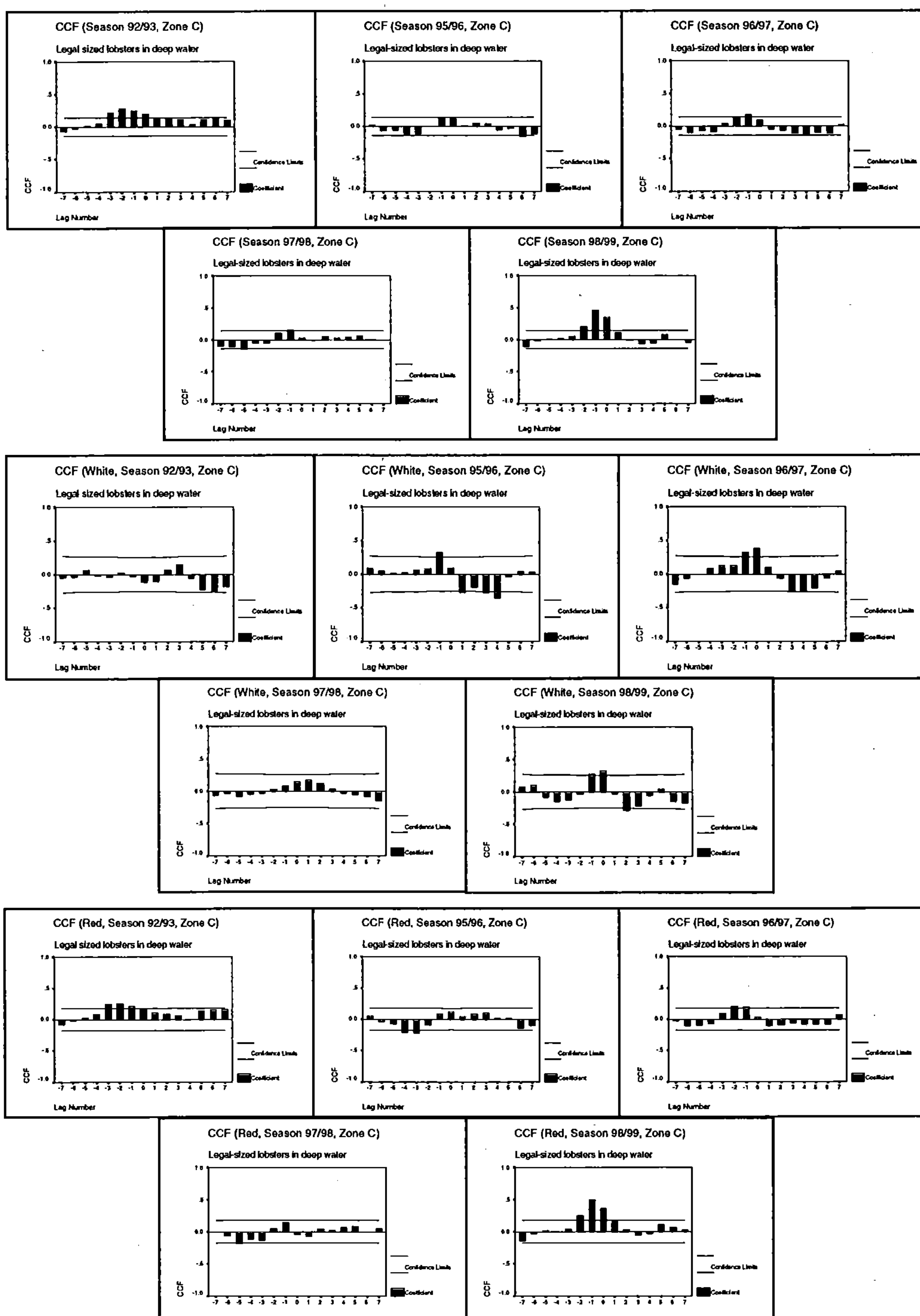
Cross correlations of adjusted catch rates of legal sized lobsters in shallow water in Zone C with swell for the whole period of every available season as well as the periods of whites and reds



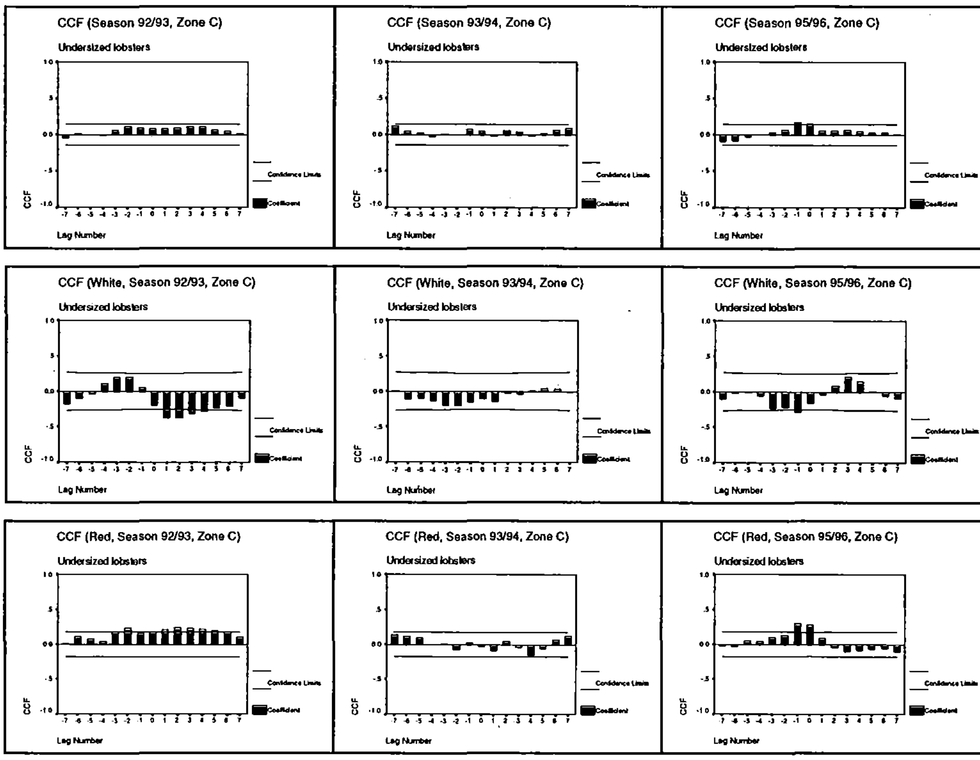




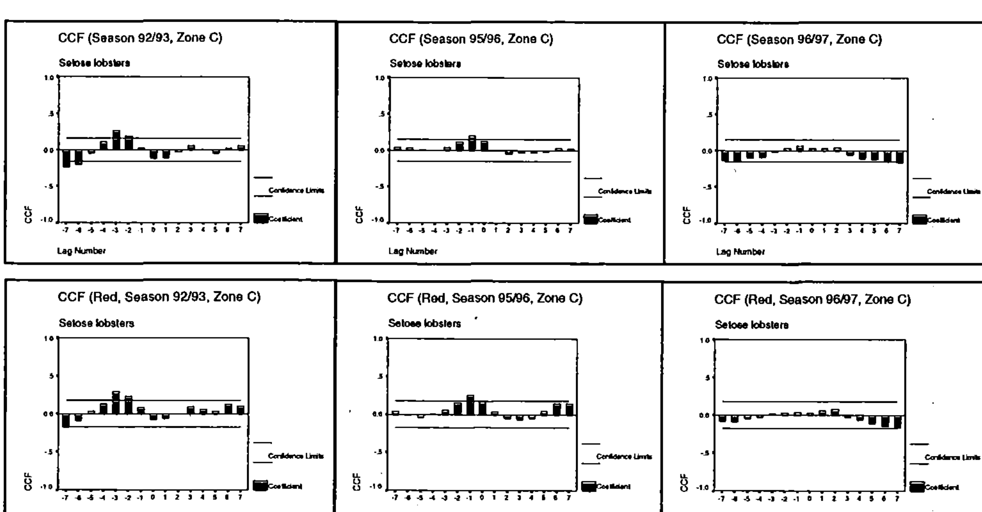
Cross correlations of adjusted catch rates of legal sized lobsters in deep water in Zone C with swell for the whole period of every available season as well as the periods of whites and reds



Cross correlations of adjusted catch rates of undersized lobsters in Zone C with swell for the whole period of every available season as well as the periods of whites and reds

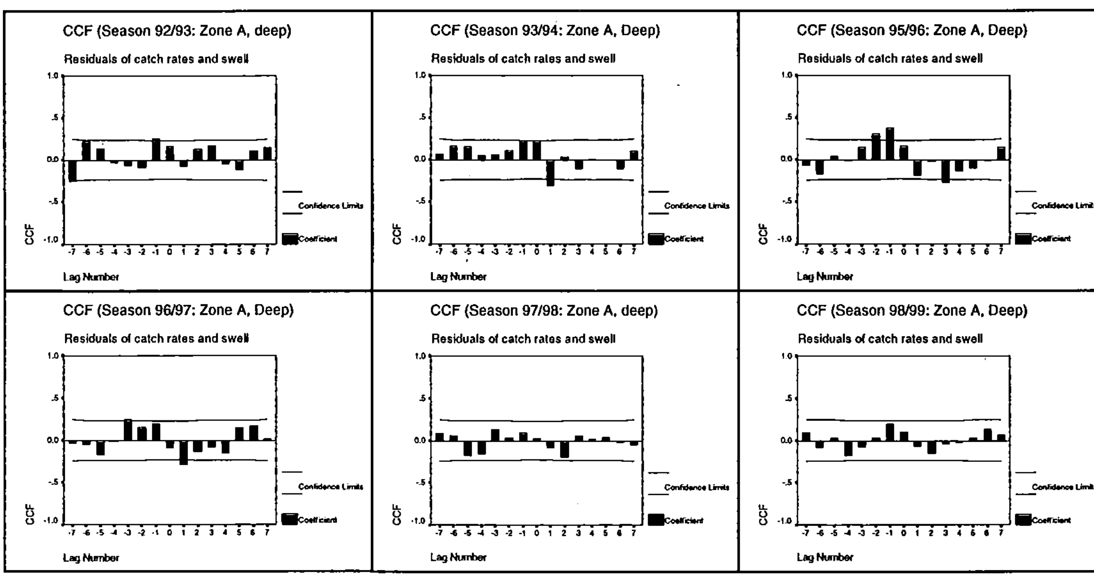


Cross correlations of adjusted catch rates of setose lobsters in Zone C with swell for the whole period of every available season and the period of reds

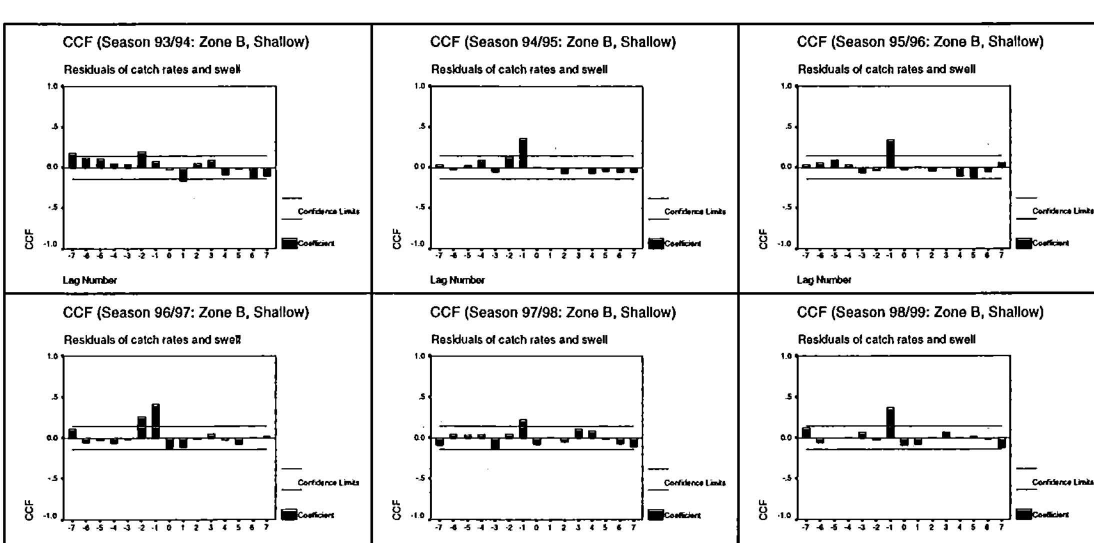


APPENDIX G: *Cross correlations of residuals with swell*

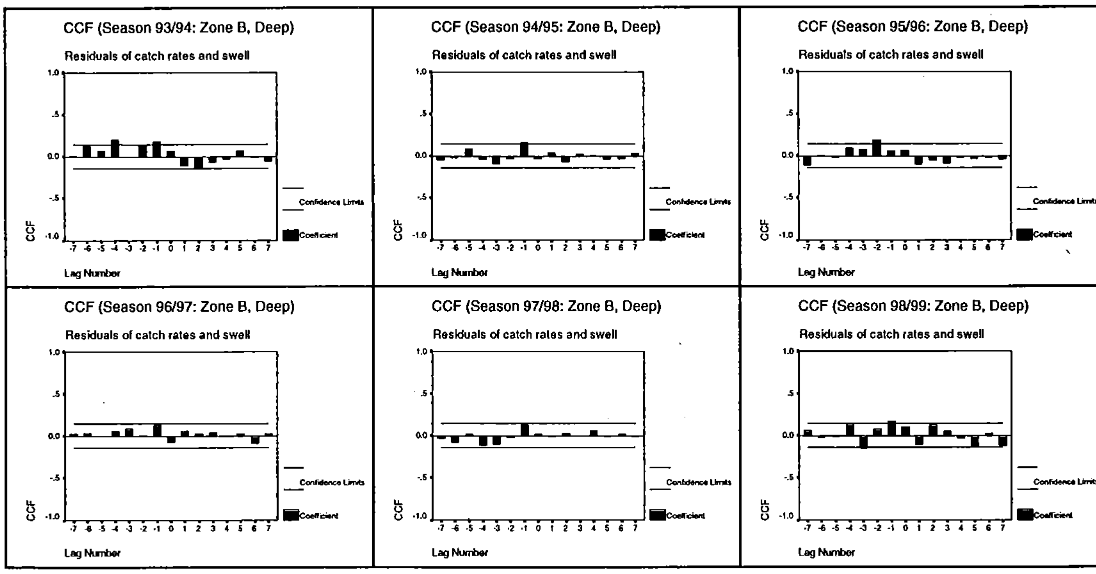
Cross correlation functions for the deep data set between the white noise of the catch rates and that of the swell in Zone A



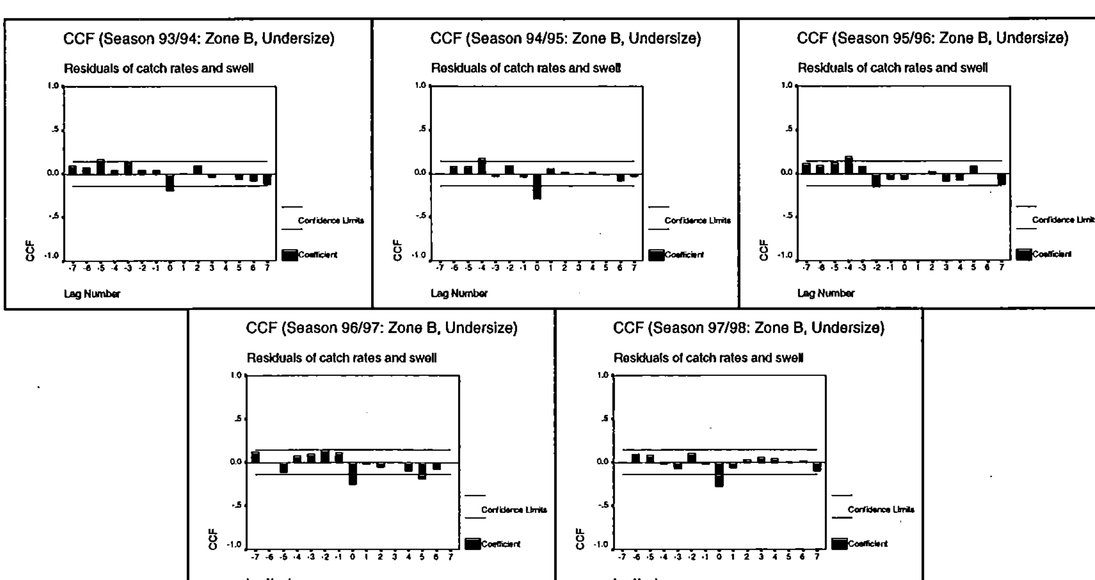
Cross correlation functions for the shallow data set between the white noise of the catch rates and that of the swell in Zone B



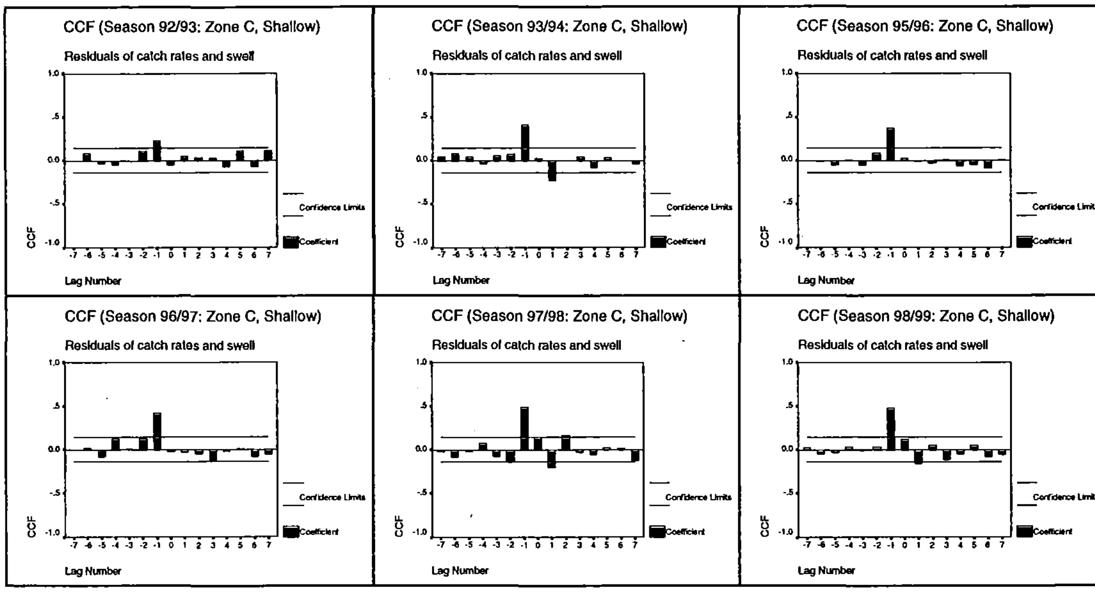
Cross correlation functions for the deep data set between the white noise of the catch rates and that of the swell in Zone B



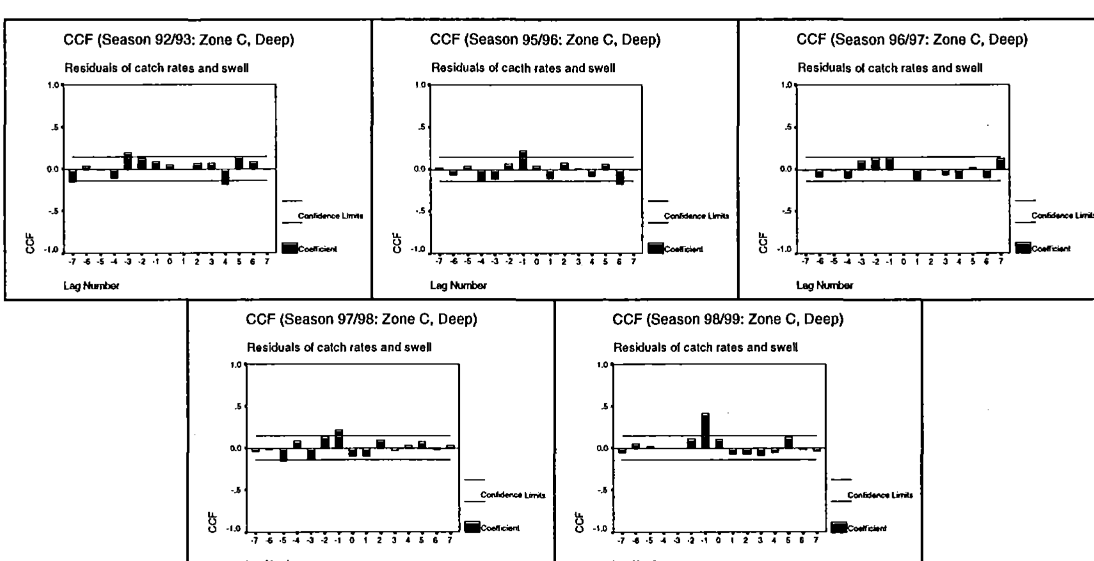
Cross correlation functions for the undersized data set between the white noise of the catch rates and that of the swell in Zone B



Cross correlation functions for the shallow data set between the white noise of the catch rates and that of the swell in Zone C



Cross correlation functions for the deep data set between the white noise of the catch rates and that of the swell in Zone C



APPENDIX H: *Minitab outputs for the regression models*

It is noted that the following regression model results where obtained assuming that the error term is IID Normal. It is noted that more appropriate models are required when the error term is found to be autocorrelated.

Regression Analysis: Season 92/93, Zone A (Deep)

The regression equation is
$Y_t = -0.223 + 0.188\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.22257	0.09253	-2.41	0.019
X_{t-1}	0.18845	0.06880	2.74	0.008

S = 0.3278 R-Sq = 9.2% R-Sq(adj) = 8.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.8062	0.8062	7.50	0.008
Residual Error	74	7.9518	0.1075		
Total	75	8.7580			

Regression Analysis: Season 92/93, Zone C (Shallow)

The regression equation is
$Y_t = -0.0991 + 0.134\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.09907	0.03338	-2.97	0.003
X_{t-1}	0.13418	0.03524	3.81	0.000

S = 0.2117 R-Sq = 7.0% R-Sq(adj) = 6.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.64944	0.64944	14.49	0.000
Residual Error	194	8.69244	0.04481		
Total	195	9.34188			

Regression Analysis: Season 92/93, Zone C (Deep)

The regression equation is
$Y_t = -0.212 + 0.268\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.21192	0.07130	-2.97	0.003
X_{t-1}	0.26784	0.07527	3.56	0.000

S = 0.4521   R-Sq = 6.1%   R-Sq(adj) = 5.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.5876	2.5876	12.66	0.000
Residual Error	194	39.6499	0.2044		
Total	195	42.2376			

Regression Analysis: Season 93/94, Zone A (Deep)

The regression equation is
$Y_t = -0.147 + 0.110\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14720	0.06555	-2.25	0.028
X_{t-1}	0.10979	0.04544	2.42	0.018

S = 0.2528   R-Sq = 7.3%   R-Sq(adj) = 6.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.37301	0.37301	5.84	0.018
Residual Error	74	4.72867	0.06390		
Total	75	5.10168			

Regression Analysis: Season 93/94, Zone B (Shallow)

The regression equation is
$Y_t = -0.115 + 0.101\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11532	0.03496	-3.30	0.001
X_{t-1}	0.10104	0.02938	3.44	0.001

S = 0.2120   R-Sq = 5.7%   R-Sq(adj) = 5.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.53164	0.53164	11.83	0.001
Residual Error	194	8.71762	0.04494		
Total	195	9.24926			

Regression Analysis: Season 93/94, Zone B (Deep)

The regression equation is
$Y_t = -0.365 + 0.339\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.36517	0.08817	-4.14	0.000
X_{t-1}	0.33899	0.07409	4.58	0.000

S = 0.5346   R-Sq = 9.7%   R-Sq(adj) = 9.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	5.9840	5.9840	20.94	0.000
Residual Error	194	55.4507	0.2858		
Total	195	61.4347			

Regression Analysis: Season 93/94, Zone B (Undersize)

The regression equation is
$Y_t = 0.0127 - 0.0140\ X_t$

Predictor	Coef	SE Coef	T	P
Constant	0.01267	0.04148	0.31	0.760
X_t	-0.01398	0.03491	-0.40	0.689

S = 0.2520   R-Sq = 0.1%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.01019	0.01019	0.16	0.689
Residual Error	194	12.32339	0.06352		
Total	195	12.33358			

Regression Analysis: Season 93/94, Zone C (Shallow)

The regression equation is
$Y_t = -0.140 + 0.145\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13960	0.02294	-6.08	0.000
X_{t-1}	0.14506	0.02211	6.56	0.000

S = 0.1570   R-Sq = 18.2%   R-Sq(adj) = 17.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.0620	1.0620	43.06	0.000
Residual Error	194	4.7845	0.0247		
Total	195	5.8465			

Regression Analysis: Season 94/95, Zone B (Shallow)

The regression equation is
$Y_t = - 0.153 + 0.150\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.15338	0.02787	-5.50	0.000
X_{t-1}	0.15047	0.02451	6.14	0.000

S = 0.1831 R-Sq = 16.3% R-Sq(adj) = 15.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.2636	1.2636	37.69	0.000
Residual Error	194	6.5041	0.0335		
Total	195	7.7677			

Regression Analysis: Season 94/95, Zone B (Deep)

The regression equation is
$Y_t = - 0.0746 + 0.0778\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.07456	0.07554	-0.99	0.325
X_{t-1}	0.07777	0.06643	1.17	0.243

S = 0.4963 R-Sq = 0.7% R-Sq(adj) = 0.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.3376	0.3376	1.37	0.243
Residual Error	194	47.7770	0.2463		
Total	195	48.1145			

Regression Analysis: Season 94/95, Zone B (Undersize)

The regression equation is
$Y_t = 0.0727 - 0.0732\ X_t$

Predictor	Coef	SE Coef	T	P
Constant	0.07271	0.02704	2.69	0.008
X_t	-0.07322	0.02377	-3.08	0.002

S = 0.1773 R-Sq = 4.7% R-Sq(adj) = 4.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.29843	0.29843	9.49	0.002
Residual Error	194	6.10103	0.03145		
Total	195	6.39946			

Regression Analysis: Season 95/96, Zone A (Deep)

The regression equation is
$Y_t = -0.140 + 0.114 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14020	0.03269	-4.29	0.000
X_{t-1}	0.11419	0.02464	4.63	0.000

S = 0.1213 R-Sq = 22.5% R-Sq(adj) = 21.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.31566	0.31566	21.47	0.000
Residual Error	74	1.08804	0.01470		
Total	75	1.40370			

Regression Analysis: Season 95/96, Zone B (Shallow)

The regression equation is
$Y_t = -0.0903 + 0.0929 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.09031	0.02549	-3.54	0.000
X_{t-1}	0.09292	0.02339	3.97	0.000

S = 0.1696 R-Sq = 7.5% R-Sq(adj) = 7.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.45386	0.45386	15.78	0.000
Residual Error	195	5.60740	0.02876		
Total	196	6.06126			

Regression Analysis: Season 95/96, Zone B (Deep)

The regression equation is
$Y_t = -0.197 + 0.196 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.19707	0.07347	-2.68	0.008
X_{t-1}	0.19648	0.06742	2.91	0.004

S = 0.4888 R-Sq = 4.2% R-Sq(adj) = 3.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.0292	2.0292	8.49	0.004
Residual Error	195	46.5867	0.2389		
Total	196	48.6159			

Regression Analysis: Season 95/96, Zone B (Undersize)

The regression equation is
$Y_t = 0.0391 - 0.0378 X_t$

Predictor	Coef	SE Coef	T	P
Constant	0.03910	0.03329	1.17	0.242
X_t	-0.03780	0.03052	-1.24	0.217

S = 0.2212   R-Sq = 0.8%   R-Sq(adj) = 0.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.07501	0.07501	1.53	0.217
Residual Error	195	9.53837	0.04891		
Total	196	9.61338			

Regression Analysis: Season 95/96, Zone C (Shallow)

The regression equation is
$Y_t = -0.135 + 0.159 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13525	0.02952	-4.58	0.000
X_{t-1}	0.15935	0.02955	5.39	0.000

S = 0.2044   R-Sq = 13.0%   R-Sq(adj) = 12.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.2150	1.2150	29.08	0.000
Residual Error	195	8.1474	0.0418		
Total	196	9.3624			

Regression Analysis: Season 95/96, Zone C (Deep)

The regression equation is
$Y_t = -0.0884 + 0.101 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.08843	0.04947	-1.79	0.075
X_{t-1}	0.10077	0.04951	2.04	0.043

S = 0.3425   R-Sq = 2.1%   R-Sq(adj) = 1.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.4859	0.4859	4.14	0.043
Residual Error	195	22.8757	0.1173		
Total	196	23.3615			

Regression Analysis: Season 96/97, Zone A (Deep)

The regression equation is
$Y_t = -0.174 + 0.117 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.17414	0.06168	-2.82	0.006
X_{t-1}	0.11675	0.04291	2.72	0.008

S = 0.2522   R-Sq = 9.1%   R-Sq(adj) = 7.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.47106	0.47106	7.40	0.008
Residual Error	74	4.70812	0.06362		
Total	75	5.17918			

Regression Analysis: Season 96/97, Zone B (Shallow)

The regression equation is
$Y_t = -0.185 + 0.175 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.18526	0.03014	-6.15	0.000
X_{t-1}	0.17522	0.02696	6.50	0.000

S = 0.2014   R-Sq = 17.9%   R-Sq(adj) = 17.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.7130	1.7130	42.22	0.000
Residual Error	194	7.8709	0.0406		
Total	195	9.5839			

Regression Analysis: Season 96/97, Zone B (Deep)

The regression equation is
$Y_t = -0.162 + 0.147 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.16206	0.07934	-2.04	0.042
X_{t-1}	0.14677	0.07098	2.07	0.040

S = 0.5302   R-Sq = 2.2%   R-Sq(adj) = 1.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.2020	1.2020	4.28	0.040
Residual Error	194	54.5385	0.2811		
Total	195	55.7405			

Regression Analysis: Season 96/97, Zone B (Undersize)

The regression equation is
$Y_t = 0.0296 - 0.0377 X_t$

Predictor	Coef	SE Coef	T	P
Constant	0.02961	0.03137	0.94	0.346
X_t	-0.03770	0.02809	-1.34	0.181

S = 0.2101   R-Sq = 0.9%   R-Sq(adj) = 0.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.07952	0.07952	1.80	0.181
Residual Error	194	8.56549	0.04415		
Total	195	8.64501			

Regression Analysis: Season 96/97, Zone C (Shallow)

The regression equation is
$Y_t = - 0.189 + 0.206 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.18877	0.02728	-6.92	0.000
X_{t-1}	0.20555	0.02707	7.59	0.000

S = 0.1964   R-Sq = 22.9%   R-Sq(adj) = 22.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.2255	2.2255	57.67	0.000
Residual Error	194	7.4869	0.0386		
Total	195	9.7124			

Regression Analysis: Season 96/97, Zone C (Deep)

The regression equation is
$Y_t = - 0.118 + 0.125 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11782	0.05063	-2.33	0.021
X_{t-1}	0.12548	0.05024	2.50	0.013

S = 0.3646   R-Sq = 3.1%   R-Sq(adj) = 2.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.8294	0.8294	6.24	0.013
Residual Error	194	25.7901	0.1329		
Total	195	26.6195			

Regression Analysis: Season 97/98, Zone A (Deep)

The regression equation is
$Y_t = -0.0369 + 0.0462\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.03686	0.06272	-0.59	0.558
X_{t-1}	0.04621	0.04212	1.10	0.276

S = 0.2216   R-Sq = 1.6%   R-Sq(adj) = 0.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.05912	0.05912	1.20	0.276
Residual Error	74	3.63467	0.04912		
Total	75	3.69379			

Regression Analysis: Season 97/98, Zone B (Shallow)

The regression equation is
$Y_t = -0.0645 + 0.0626\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.06446	0.03186	-2.02	0.044
X_{t-1}	0.06262	0.02700	2.32	0.021

S = 0.1993   R-Sq = 2.7%   R-Sq(adj) = 2.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.21363	0.21363	5.38	0.021
Residual Error	194	7.70553	0.03972		
Total	195	7.91915			

Regression Analysis: Season 97/98, Zone B (Deep)

The regression equation is
$Y_t = -0.0389 + 0.0364\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.03887	0.06545	-0.59	0.553
X_{t-1}	0.03643	0.05548	0.66	0.512

S = 0.4095   R-Sq = 0.2%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.0723	0.0723	0.43	0.512
Residual Error	194	32.5273	0.1677		
Total	195	32.5996			

Regression Analysis: Season 97/98, Zone B (Undersize)

The regression equation is
$Y_t = 0.0898 - 0.0873\ X_t$

Predictor	Coef	SE Coef	T	P
Constant	0.08977	0.02984	3.01	0.003
X_t	-0.08733	0.02522	-3.46	0.001

S = 0.1868   R-Sq = 5.8%   R-Sq(adj) = 5.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.41842	0.41842	12.00	0.001
Residual Error	194	6.76707	0.03488		
Total	195	7.18549			

Regression Analysis: Season 97/98, Zone C (Shallow)

The regression equation is
$Y_t = -\ 0.134 + 0.149\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13442	0.02429	-5.53	0.000
X_{t-1}	0.14926	0.02331	6.40	0.000

S = 0.1632   R-Sq = 17.4%   R-Sq(adj) = 17.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.0926	1.0926	41.00	0.000
Residual Error	194	5.1701	0.0267		
Total	195	6.2628			

Regression Analysis: Season 97/98, Zone C (Deep)

The regression equation is
$Y_t = -\ 0.125 + 0.132\ X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.12494	0.05946	-2.10	0.037
X_{t-1}	0.13195	0.05706	2.31	0.022

S = 0.3996   R-Sq = 2.7%   R-Sq(adj) = 2.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.8538	0.8538	5.35	0.022
Residual Error	194	30.9746	0.1597		
Total	195	31.8284			

Regression Analysis: Season 98/99, Zone A (Deep)

The regression equation is
$Y_t = -0.0651 + 0.0516 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.06509	0.07192	-0.91	0.368
X_{t-1}	0.05158	0.05679	0.91	0.367

S = 0.2630   R-Sq = 1.1%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.05706	0.05706	0.82	0.367
Residual Error	72	4.98159	0.06919		
Total	73	5.03865			

Regression Analysis: Season 98/99, Zone B (Shallow)

The regression equation is
$Y_t = -0.113 + 0.118 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11337	0.02955	-3.84	0.000
X_{t-1}	0.11827	0.02665	4.44	0.000

S = 0.1906   R-Sq = 9.2%   R-Sq(adj) = 8.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.71563	0.71563	19.69	0.000
Residual Error	194	7.04917	0.03634		
Total	195	7.76481			

Regression Analysis: Season 98/99, Zone B (Deep)

The regression equation is
$Y_t = -0.190 + 0.202 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.19029	0.07795	-2.44	0.016
X_{t-1}	0.20228	0.07031	2.88	0.004

S = 0.5029   R-Sq = 4.1%   R-Sq(adj) = 3.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.0936	2.0936	8.28	0.004
Residual Error	194	49.0725	0.2530		
Total	195	51.1661			

Regression Analysis: Season 98/99, Zone C (Shallow)

The regression equation is
$Y_t = -0.165 + 0.201 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.16466	0.02220	-7.42	0.000
X_{t-1}	0.20108	0.02343	8.58	0.000

S = 0.1500 R-Sq = 27.5% R-Sq(adj) = 27.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.6567	1.6567	73.67	0.000
Residual Error	194	4.3628	0.0225		
Total	195	6.0195			

Regression Analysis: Season 98/99, Zone C (Deep)

The regression equation is
$Y_t = -0.292 + 0.363 X_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.29250	0.04718	-6.20	0.000
X_{t-1}	0.36272	0.04978	7.29	0.000

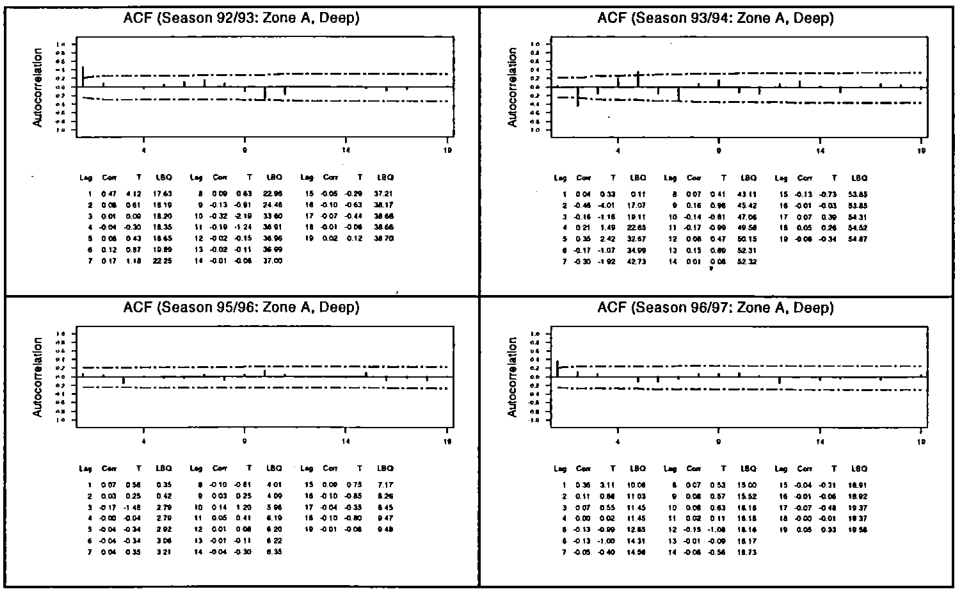
S = 0.3187 R-Sq = 21.5% R-Sq(adj) = 21.1%

Analysis of Variance

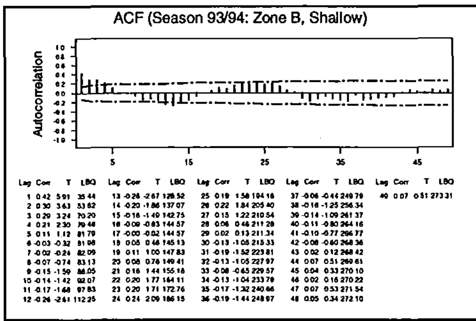
Source	DF	SS	MS	F	P
Regression	1	5.3905	5.3905	53.09	0.000
Residual Error	194	19.6994	0.1015		
Total	195	25.0898			

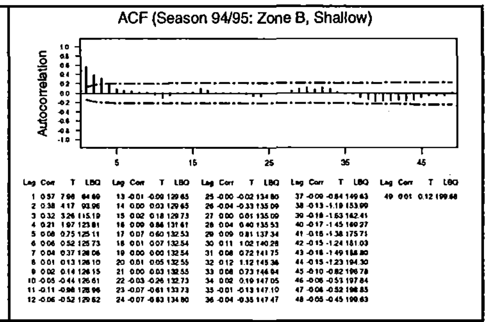
APPENDIX I: *ACFs of the residuals from the regression models*

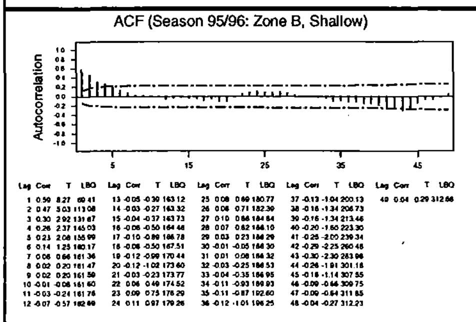
ACFs of the residuals from the models for deep data sets in Zone A

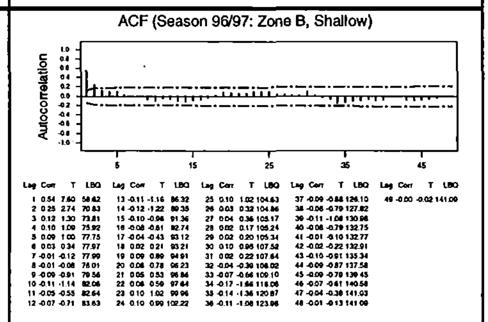


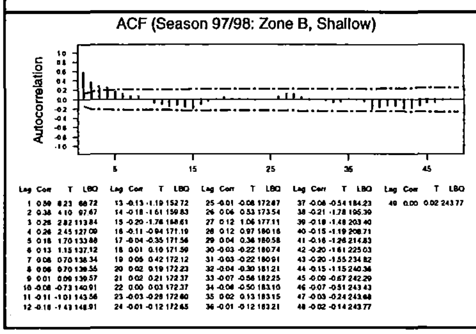
ACFs of the residuals from the models for shallow data sets in Zone B

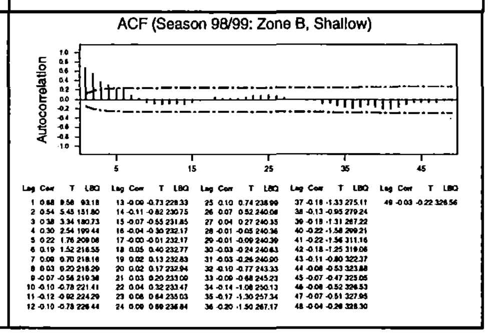




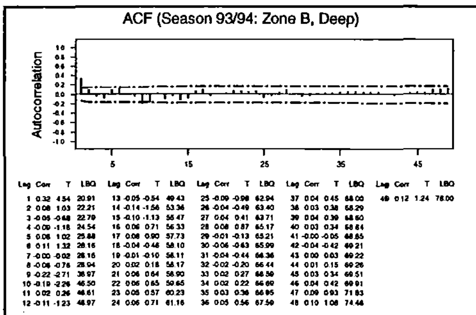


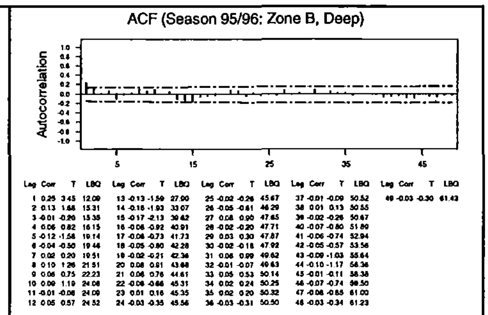


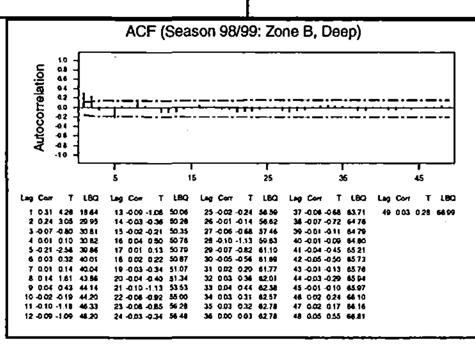




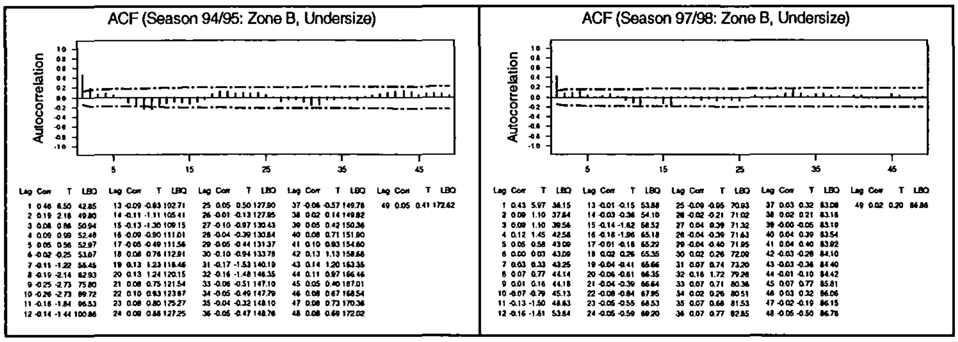
ACFs of the residuals from the models for deep data sets in Zone B



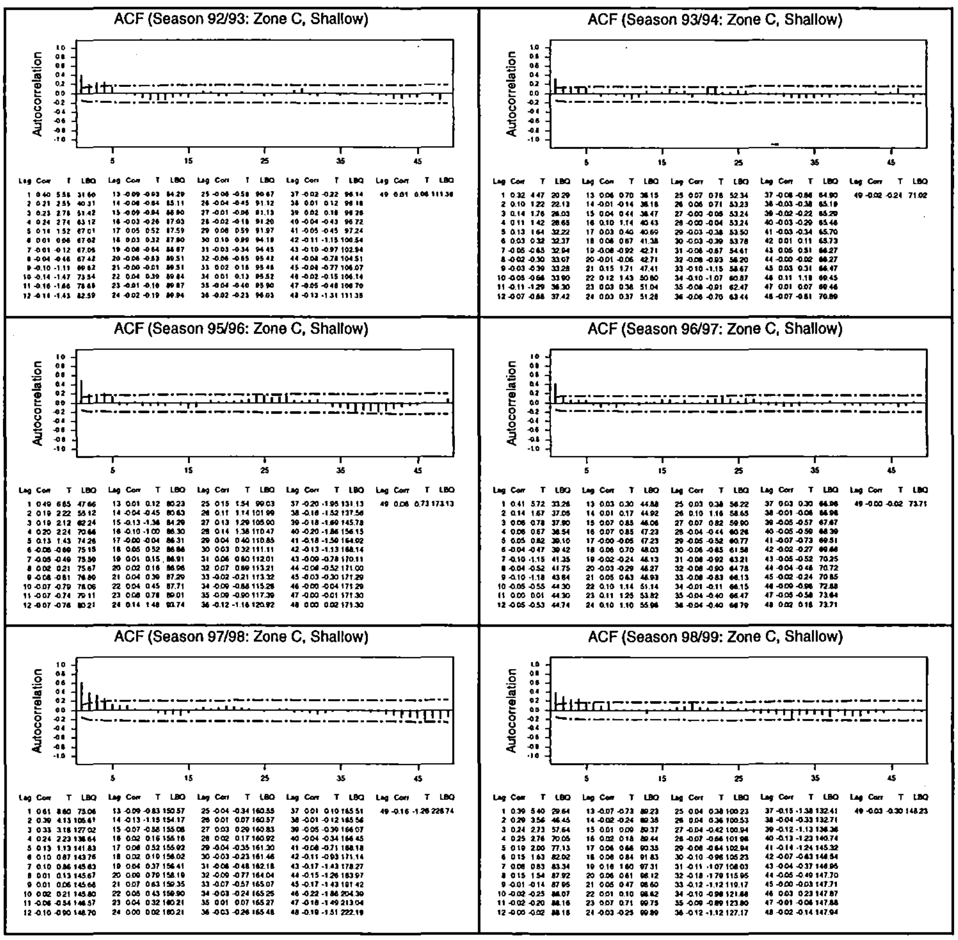




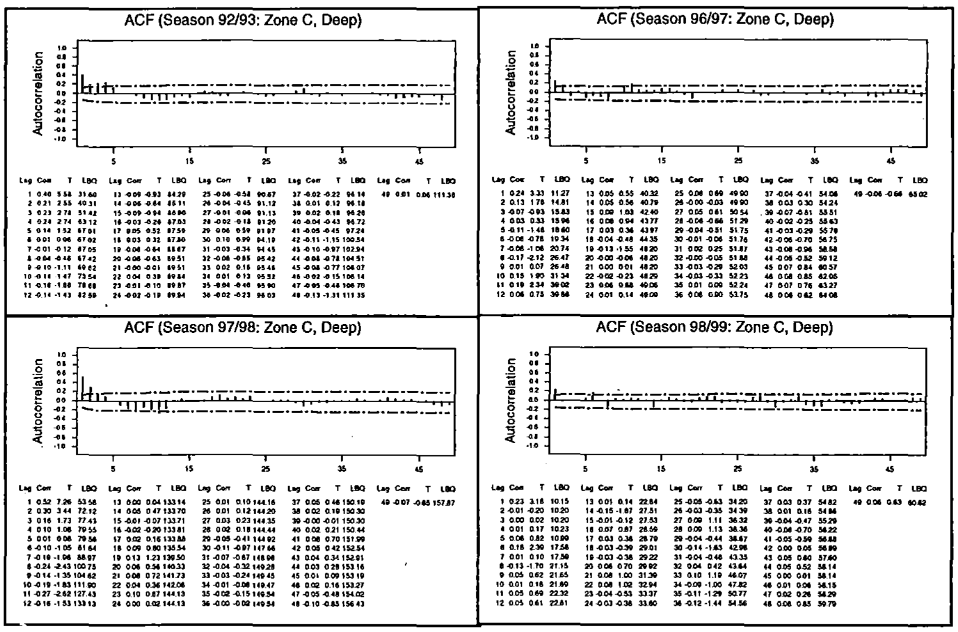
ACFs of the residuals from the models for undersized data sets in Zone B



ACFs of the residuals from the models for shallow data sets in Zone C



ACFs of the residuals from the models for deep data sets in Zone C



APPENDIX J: *Minitab outputs for the regression models with the explanatory variable Y_{t-1}*

Regression Analysis: Season 92/93, Zone A (Deep)

The regression equation is

$Y_t = - 0.122 + 0.105 X_{t-1} + 0.454 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.12162	0.08674	-1.40	0.165
X_{t-1}	0.10454	0.06510	1.61	0.113
Y_{t-1}	0.4541	0.1069	4.25	0.000

S = 0.2955   R-Sq = 27.2%   R-Sq(adj) = 25.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.3817	1.1909	13.63	0.000
Residual Error	73	6.3763	0.0873		
Total	75	8.7580			

Regression Analysis: Season 92/93, Zone C (Shallow)

The regression equation is

$Y_t = - 0.0765 + 0.102 X_{t-1} + 0.415 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.07652	0.03021	-2.53	0.012
X_{t-1}	0.10191	0.03205	3.18	0.002
Y_{t-1}	0.41513	0.06073	6.84	0.000

S = 0.1904   R-Sq = 25.1%   R-Sq(adj) = 24.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.3439	1.1720	32.32	0.000
Residual Error	193	6.9980	0.0363		
Total	195	9.3419			

Regression Analysis: Season 92/93, Zone C, Deep

The regression equation is

$Y_t = -0.128 + 0.162\ X_{t-1} + 0.535\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.12776	0.06034	-2.12	0.036
X_{t-1}	0.16195	0.06401	2.53	0.012
Y_{t-1}	0.53478	0.05825	9.18	0.000

S = 0.3781 R-Sq = 34.7% R-Sq(adj) = 34.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	14.6403	7.3201	51.19	0.000
Residual Error	193	27.5973	0.1430		
Total	195	42.2376			

Regression Analysis: Season 93/94, Zone A (Deep)

The regression equation is

$Y_t = -0.150 + 0.112\ X_{t-1} - 0.013\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14963	0.06955	-2.15	0.035
X_{t-1}	0.11157	0.04849	2.30	0.024
Y_{t-1}	-0.0131	0.1186	-0.11	0.912

S = 0.2545 R-Sq = 7.3% R-Sq(adj) = 4.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.37380	0.18690	2.89	0.062
Residual Error	73	4.72788	0.06477		
Total	75	5.10168			

Regression Analysis: Season 93/94, Zone B (Shallow)

The regression equation is

$Y_t = -0.0917 + 0.0812\ X_{t-1} + 0.443\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.09169	0.03137	-2.92	0.004
X_{t-1}	0.08124	0.02636	3.08	0.002
Y_{t-1}	0.44323	0.06229	7.12	0.000

S = 0.1892 R-Sq = 25.3% R-Sq(adj) = 24.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.3435	1.1718	32.75	0.000
Residual Error	193	6.9057	0.0358		
Total	195	9.2493			

Regression Analysis: Season 93/94, Zone B (Deep)

The regression equation is
$Y_t = -0.286 + 0.265\ X_{t-1} + 0.327\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.28574	0.08474	-3.37	0.001
X_{t-1}	0.26488	0.07150	3.70	0.000
Y_{t-1}	0.32671	0.06569	4.97	0.000

S = 0.5047   R-Sq = 20.0%   R-Sq(adj) = 19.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	12.2828	6.1414	24.11	0.000
Residual Error	193	49.1518	0.2547		
Total	195	61.4347			

Regression Analysis: Season 93/94, Zone B (Undersize)

The regression equation is
$Y_t = 0.0184 - 0.0173\ X_t + 0.464\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	0.01844	0.03684	0.50	0.617
X_t	-0.01734	0.03100	-0.56	0.577
Y_{t-1}	0.46404	0.06371	7.28	0.000

S = 0.2238   R-Sq = 21.6%   R-Sq(adj) = 20.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.6671	1.3336	26.63	0.000
Residual Error	193	9.6665	0.0501		
Total	195	12.3336			

Regression Analysis: Season 93/94, Zone C (Shallow)

The regression equation is
$Y_t = -0.118 + 0.124\ X_{t-1} + 0.275\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11843	0.02249	-5.27	0.000
X_{t-1}	0.12380	0.02171	5.70	0.000
Y_{t-1}	0.27519	0.06341	4.34	0.000

S = 0.1503   R-Sq = 25.4%   R-Sq(adj) = 24.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.48741	0.74370	32.93	0.000
Residual Error	193	4.35913	0.02259		
Total	195	5.84653			

Regression Analysis: Season 94/95, Zone B (Shallow)

The regression equation is
$Y_t = -0.104 + 0.103 X_{t-1} + 0.533 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.10448	0.02358	-4.43	0.000
X_{t-1}	0.10277	0.02085	4.93	0.000
Y_{t-1}	0.53314	0.05576	9.56	0.000

S = 0.1512   R-Sq = 43.2%   R-Sq(adj) = 42.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	3.3544	1.6772	73.35	0.000
Residual Error	193	4.4133	0.0229		
Total	195	7.7677			

Regression Analysis: Season 94/95, Zone B (Deep)

The regression equation is
$Y_t = -0.0454 + 0.0472 X_{t-1} + 0.523 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.04544	0.06457	-0.70	0.482
X_{t-1}	0.04716	0.05682	0.83	0.408
Y_{t-1}	0.52294	0.06112	8.56	0.000

S = 0.4236   R-Sq = 28.0%   R-Sq(adj) = 27.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	13.4772	6.7386	37.55	0.000
Residual Error	193	34.6373	0.1795		
Total	195	48.1145			

Regression Analysis: Season 94/95, Zone B (Undersize)

The regression equation is
$Y_t = 0.0601 - 0.0602 X_t + 0.301 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	0.06010	0.02598	2.31	0.022
X_t	-0.06021	0.02289	-2.63	0.009
Y_{t-1}	0.30123	0.06788	4.44	0.000

S = 0.1694   R-Sq = 13.5%   R-Sq(adj) = 12.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.86325	0.43162	15.05	0.000
Residual Error	193	5.53621	0.02869		
Total	195	6.39946			

Regression Analysis: Season 95/96, Zone A (Deep)

The regression equation is

$Y_t = -0.133 + 0.108\ X_{t-1} + 0.054\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13300	0.03621	-3.67	0.000
X_{t-1}	0.10839	0.02762	3.92	0.000
Y_{t-1}	0.0544	0.1146	0.47	0.637

S = 0.1219   R-Sq = 22.7%   R-Sq(adj) = 20.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.31900	0.15950	10.73	0.000
Residual Error	73	1.08469	0.01486		
Total	75	1.40370			

Regression Analysis: Season 95/96, Zone B (Shallow)

The regression equation is

$Y_t = -0.0674 + 0.0680\ X_{t-1} + 0.546\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.06742	0.02118	-3.18	0.002
X_{t-1}	0.06796	0.01948	3.49	0.001
Y_{t-1}	0.54609	0.05689	9.60	0.000

S = 0.1400   R-Sq = 37.3%   R-Sq(adj) = 36.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.2595	1.1298	57.65	0.000
Residual Error	194	3.8018	0.0196		
Total	196	6.0613			

Regression Analysis: Season 95/96, Zone B (Deep)

The regression equation is

$Y_t = -0.156 + 0.156\ X_{t-1} + 0.281\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.15579	0.07138	-2.18	0.030
X_{t-1}	0.15623	0.06559	2.38	0.018
Y_{t-1}	0.28061	0.06849	4.10	0.000

S = 0.4701   R-Sq = 11.8%   R-Sq(adj) = 10.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	5.7390	2.8695	12.98	0.000
Residual Error	194	42.8769	0.2210		
Total	196	48.6159			

Regression Analysis: Season 95/96, Zone B (Undersize)

The regression equation is
$Y_t = 0.0252 - 0.0249 X_t + 0.433 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	0.02519	0.03013	0.84	0.404
X_t	-0.02487	0.02762	-0.90	0.369
Y_{t-1}	0.43317	0.06438	6.73	0.000

S = 0.1997   R-Sq = 19.6%   R-Sq(adj) = 18.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.87966	0.93983	23.58	0.000
Residual Error	194	7.73372	0.03986		
Total	196	9.61338			

Regression Analysis: Season 95/96, Zone C (Shallow)

The regression equation is
$Y_t = -0.0978 + 0.113 X_{t-1} + 0.446 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.09776	0.02682	-3.65	0.000
X_{t-1}	0.11290	0.02711	4.16	0.000
Y_{t-1}	0.44571	0.06206	7.18	0.000

S = 0.1821   R-Sq = 31.3%   R-Sq(adj) = 30.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.9260	1.4630	44.10	0.000
Residual Error	194	6.4363	0.0332		
Total	196	9.3624			

Regression Analysis: Season 95/96, Zone C (Deep)

The regression equation is
$Y_t = -0.0773 + 0.0882 X_{t-1} + 0.144 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.07728	0.04939	-1.56	0.119
X_{t-1}	0.08818	0.04952	1.78	0.077
Y_{t-1}	0.14373	0.07107	2.02	0.045

S = 0.3398   R-Sq = 4.1%   R-Sq(adj) = 3.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.9582	0.4791	4.15	0.017
Residual Error	194	22.4033	0.1155		
Total	196	23.3615			

Regression Analysis: Season 96/97, Zone A (Deep)

The regression equation is
$Y_t = -0.144 + 0.101 X_{t-1} + 0.345 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14441	0.05856	-2.47	0.016
X_{t-1}	0.10134	0.04052	2.50	0.015
Y_{t-1}	0.3452	0.1038	3.33	0.001

S = 0.2367   R-Sq = 21.1%   R-Sq(adj) = 18.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.09037	0.54518	9.73	0.000
Residual Error	73	4.08881	0.05601		
Total	75	5.17918			

Regression Analysis: Season 96/97, Zone B (Shallow)

The regression equation is
$Y_t = -0.143 + 0.139 X_{t-1} + 0.508 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14337	0.02551	-5.62	0.000
X_{t-1}	0.13857	0.02281	6.08	0.000
Y_{t-1}	0.50784	0.05458	9.30	0.000

S = 0.1678   R-Sq = 43.3%   R-Sq(adj) = 42.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	4.1502	2.0751	73.71	0.000
Residual Error	193	5.4337	0.0282		
Total	195	9.5839			

Regression Analysis: Season 96/97, Zone B (Deep)

The regression equation is
$Y_t = -0.133 + 0.121 X_{t-1} + 0.391 Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13252	0.07310	-1.81	0.071
X_{t-1}	0.12070	0.06539	1.85	0.066
Y_{t-1}	0.39148	0.06473	6.05	0.000

S = 0.4874   R-Sq = 17.7%   R-Sq(adj) = 16.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	9.8903	4.9452	20.82	0.000
Residual Error	193	45.8502	0.2376		
Total	195	55.7405			

Regression Analysis: Season 96/97, Zone B (Undersize)

The regression equation is
$Y_t = 0.0157 - 0.0202\ X_t + 0.423\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	0.01573	0.02859	0.55	0.583
X_t	-0.02024	0.02567	-0.79	0.432
Y_{t-1}	0.42315	0.06541	6.47	0.000

S = 0.1910   R-Sq = 18.6%   R-Sq(adj) = 17.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.60608	0.80304	22.02	0.000
Residual Error	193	7.03893	0.03647		
Total	195	8.64501			

Regression Analysis: Season 96/97, Zone C (Shallow)

The regression equation is
$Y_t = -\ 0.147 + 0.162\ X_{t-1} + 0.366\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.14701	0.02597	-5.66	0.000
X_{t-1}	0.16167	0.02587	6.25	0.000
Y_{t-1}	0.36621	0.06011	6.09	0.000

S = 0.1804   R-Sq = 35.3%   R-Sq(adj) = 34.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	3.4332	1.7166	52.76	0.000
Residual Error	193	6.2792	0.0325		
Total	195	9.7124			

Regression Analysis: Season 96/97, Zone C (Deep)

The regression equation is
$Y_t = -\ 0.105 + 0.111\ X_{t-1} + 0.244\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.10484	0.04937	-2.12	0.035
X_{t-1}	0.11125	0.04901	2.27	0.024
Y_{t-1}	0.24445	0.06995	3.49	0.001

S = 0.3545   R-Sq = 8.9%   R-Sq(adj) = 7.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.3644	1.1822	9.41	0.000
Residual Error	193	24.2552	0.1257		
Total	195	26.6195			

Regression Analysis: Season 97/98, Zone A (Deep)

The regression equation is

$Y_t = - 0.0308 + 0.0372\ X_{t-1} + 0.348\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.03084	0.05934	-0.52	0.605
X_{t-1}	0.03720	0.03993	0.93	0.355
Y_{t-1}	0.3478	0.1113	3.12	0.003

S = 0.2096 R-Sq = 13.2% R-Sq(adj) = 10.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.48771	0.24386	5.55	0.006
Residual Error	73	3.20608	0.04392		
Total	75	3.69379			

Regression Analysis: Season 97/98, Zone B (Shallow)

The regression equation is

$Y_t = - 0.0498 + 0.0472\ X_{t-1} + 0.576\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.04983	0.02592	-1.92	0.056
X_{t-1}	0.04717	0.02199	2.15	0.033
Y_{t-1}	0.57635	0.05733	10.05	0.000

S = 0.1619 R-Sq = 36.1% R-Sq(adj) = 35.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.8617	1.4309	54.60	0.000
Residual Error	193	5.0574	0.0262		
Total	195	7.9192			

Regression Analysis: Season 97/98, Zone B (Deep)

The regression equation is

$Y_t = - 0.0143 + 0.0094\ X_{t-1} + 0.590\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.01428	0.05325	-0.27	0.789
X_{t-1}	0.00936	0.04517	0.21	0.836
Y_{t-1}	0.59016	0.05879	10.04	0.000

S = 0.3328 R-Sq = 34.4% R-Sq(adj) = 33.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	11.2288	5.6144	50.70	0.000
Residual Error	193	21.3708	0.1107		
Total	195	32.5996			

Regression Analysis: Season 97/98, Zone B (Undersize)

The regression equation is
$Y_t = 0.0613 - 0.0595\ X_t + 0.397\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	0.06129	0.02779	2.21	0.029
X_t	-0.05946	0.02360	-2.52	0.013
Y_{t-1}	0.39710	0.06520	6.09	0.000

S = 0.1715   R-Sq = 21.0%   R-Sq(adj) = 20.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1.50939	0.75469	25.66	0.000
Residual Error	193	5.67610	0.02941		
Total	195	7.18549			

Regression Analysis: Season 97/98, Zone C (Shallow)

The regression equation is
$Y_t = -\ 0.0866 + 0.0953\ X_{t-1} + 0.511\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.08659	0.02114	-4.10	0.000
X_{t-1}	0.09527	0.02053	4.64	0.000
Y_{t-1}	0.51135	0.05693	8.98	0.000

S = 0.1374   R-Sq = 41.8%   R-Sq(adj) = 41.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.6166	1.3083	69.25	0.000
Residual Error	193	3.6461	0.0189		
Total	195	6.2628			

Regression Analysis: Season 97/98, Zone C (Deep)

The regression equation is
$Y_t = -\ 0.117 + 0.123\ X_{t-1} + 0.499\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.11739	0.05100	-2.30	0.022
X_{t-1}	0.12270	0.04894	2.51	0.013
Y_{t-1}	0.49941	0.05936	8.41	0.000

S = 0.3427   R-Sq = 28.8%   R-Sq(adj) = 28.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	9.1650	4.5825	39.02	0.000
Residual Error	193	22.6634	0.1174		
Total	195	31.8284			

Regression Analysis: Season 98/99, Zone A (Deep)

The regression equation is
$Y_t = -0.0576 + 0.0453\ X_{t-1} + 0.089\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.05757	0.07284	-0.79	0.432
X_{t-1}	0.04532	0.05758	0.79	0.434
Y_{t-1}	0.0890	0.1190	0.75	0.457

S = 0.2638   R-Sq = 1.9%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.09605	0.04802	0.69	0.505
Residual Error	71	4.94260	0.06961		
Total	73	5.03865			

Regression Analysis: Season 98/99, Zone B (Shallow)

The regression equation is
$Y_t = -0.0873 + 0.0900\ X_{t-1} + 0.643\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.08735	0.02209	-3.95	0.000
X_{t-1}	0.09005	0.01996	4.51	0.000
Y_{t-1}	0.64286	0.05128	12.54	0.000

S = 0.1419   R-Sq = 50.0%   R-Sq(adj) = 49.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	3.8798	1.9399	96.37	0.000
Residual Error	193	3.8851	0.0201		
Total	195	7.7648			

Regression Analysis: Season 98/99, Zone B (Deep)

The regression equation is
$Y_t = -0.133 + 0.142\ X_{t-1} + 0.302\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13344	0.07559	-1.77	0.079
X_{t-1}	0.14197	0.06856	2.07	0.040
Y_{t-1}	0.30238	0.06848	4.42	0.000

S = 0.4806   R-Sq = 12.9%   R-Sq(adj) = 12.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	6.5967	3.2984	14.28	0.000
Residual Error	193	44.5694	0.2309		
Total	195	51.1661			

Regression Analysis: Season 98/99, Zone C (Shallow)

The regression equation is

$Y_t = -0.132 + 0.161\ X_{t-1} + 0.274\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.13182	0.02258	-5.84	0.000
X_{t-1}	0.16078	0.02429	6.62	0.000
Y_{t-1}	0.27369	0.06338	4.32	0.000

S = 0.1436 R-Sq = 33.9% R-Sq(adj) = 33.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.0410	1.0205	49.51	0.000
Residual Error	193	3.9785	0.0206		
Total	195	6.0195			

Regression Analysis: Season 98/99, Zone C (Deep)

The regression equation is

$Y_t = -0.263 + 0.327\ X_{t-1} + 0.135\ Y_{t-1}$

Predictor	Coef	SE Coef	T	P
Constant	-0.26293	0.04899	-5.37	0.000
X_{t-1}	0.32652	0.05248	6.22	0.000
Y_{t-1}	0.13520	0.06629	2.04	0.043

S = 0.3161 R-Sq = 23.1% R-Sq(adj) = 22.3%

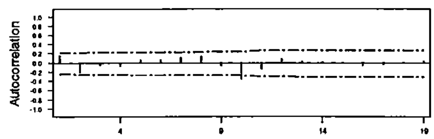
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	5.8060	2.9030	29.05	0.000
Residual Error	193	19.2838	0.0999		
Total	195	25.0898			

APPENDIX K: *ACFs of the residuals from the regression models with the explanatory variable Y_{t-1}*

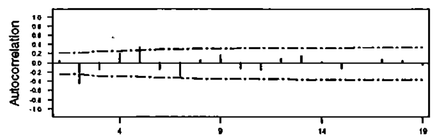
ACFs of the residuals from the models for deep data sets in Zone A

ACF (Season 92/93: Zone A, Deep)



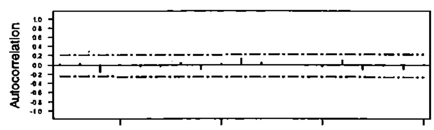
Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.17	1.47	2.25	8	0.14	1.12	10.22	15	-0.04	-0.26	25.24
2	-0.22	-1.87	6.15	9	-0.07	-0.58	10.70	16	-0.07	-0.48	25.72
3	-0.05	-0.44	6.39	10	-0.36	-2.78	22.22	17	-0.05	-0.36	26.00
4	-0.08	-0.69	6.98	11	-0.15	-1.00	24.16	18	-0.02	-0.15	26.05
5	0.05	0.44	7.23	12	0.09	0.64	24.84	19	0.04	0.27	26.20
6	0.06	0.46	7.50	13	0.04	0.25	25.06				
7	0.11	0.86	8.48	14	0.02	0.15	25.11				

ACF (Season 93/94: Zone A, Deep)



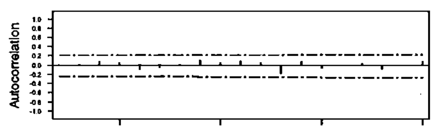
Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.04	0.39	0.16	8	0.06	0.39	43.25	15	-0.12	-0.72	63.84
2	-0.46	-4.00	17.12	9	0.16	0.97	45.48	16	-0.01	-0.03	53.84
3	-0.16	-1.18	19.25	10	-0.13	-0.81	47.10	17	0.07	0.39	54.30
4	0.21	1.50	22.84	11	-0.16	-0.98	48.58	18	0.04	0.25	54.50
5	0.35	2.41	32.86	12	0.08	0.47	50.17	19	-0.06	-0.34	54.85
6	-0.16	-1.07	35.16	13	0.15	0.89	52.32				
7	-0.30	-1.92	42.89	14	0.01	0.08	52.34				

ACF (Season 95/96: Zone A, Deep)



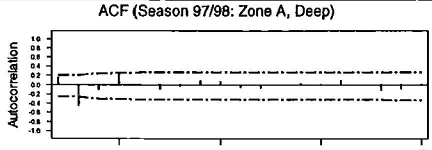
Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.02	0.14	0.02	8	-0.10	-0.84	3.85	15	0.10	0.80	7.11
2	0.03	0.28	0.10	9	0.03	0.27	3.95	16	-0.11	-0.87	8.25
3	-0.17	-1.49	2.48	10	0.14	1.20	5.81	17	-0.04	-0.29	8.38
4	0.00	0.02	2.48	11	0.04	0.35	5.99	18	-0.09	-0.74	9.26
5	-0.04	-0.35	2.63	12	0.00	0.03	5.99	19	0.00	0.02	9.26
6	-0.04	-0.34	2.77	13	-0.01	-0.11	6.00				
7	0.05	0.42	2.98	14	-0.04	-0.35	6.18				

ACF (Season 96/97: Zone A, Deep)



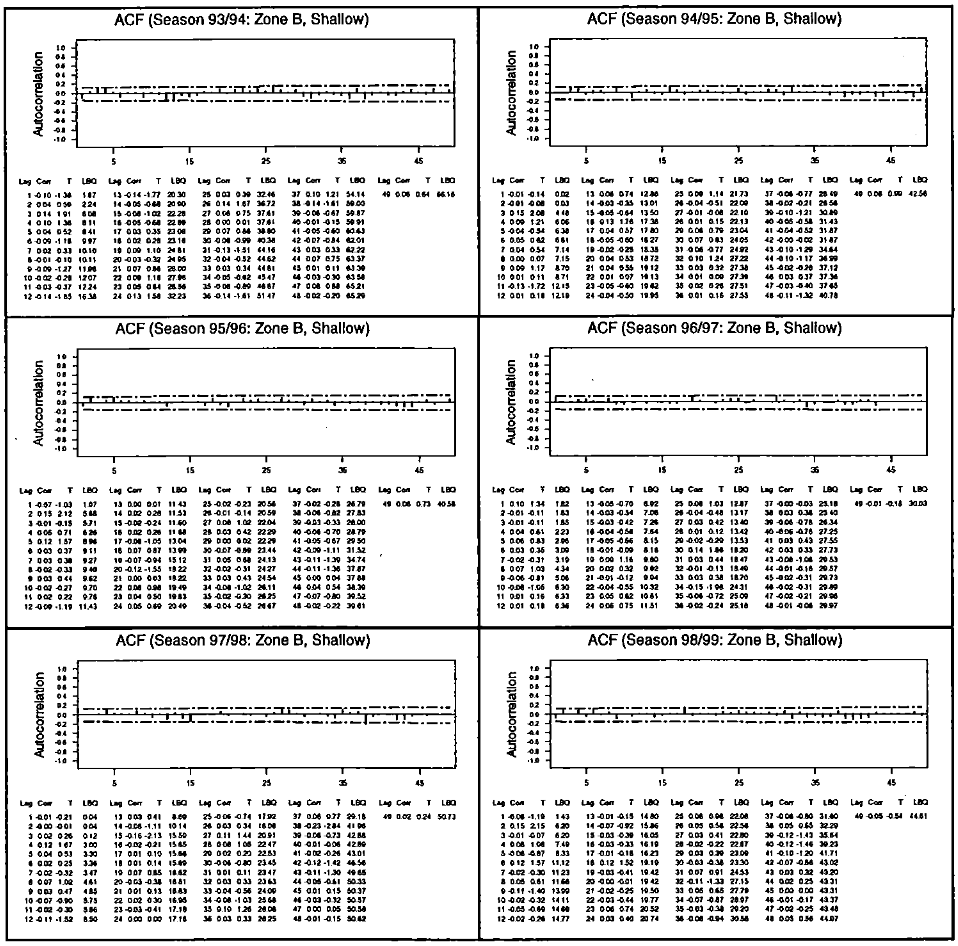
Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.01	0.09	0.01	8	0.10	0.83	2.68	15	-0.02	-0.15	7.97
2	-0.01	-0.11	0.02	9	0.05	0.38	2.86	16	0.03	0.25	8.07
3	0.07	0.64	0.46	10	0.08	0.70	3.49	17	-0.08	-0.65	8.73
4	0.04	0.35	0.60	11	0.04	0.36	3.66	18	0.00	0.02	8.73
5	-0.10	-0.88	1.46	12	-0.19	-1.57	6.92	19	0.07	0.54	9.21
6	-0.06	-0.56	1.61	13	0.07	0.56	7.37				
7	-0.02	-0.19	1.86	14	-0.08	-0.62	7.93				

ACF (Season 97/98: Zone A, Deep)

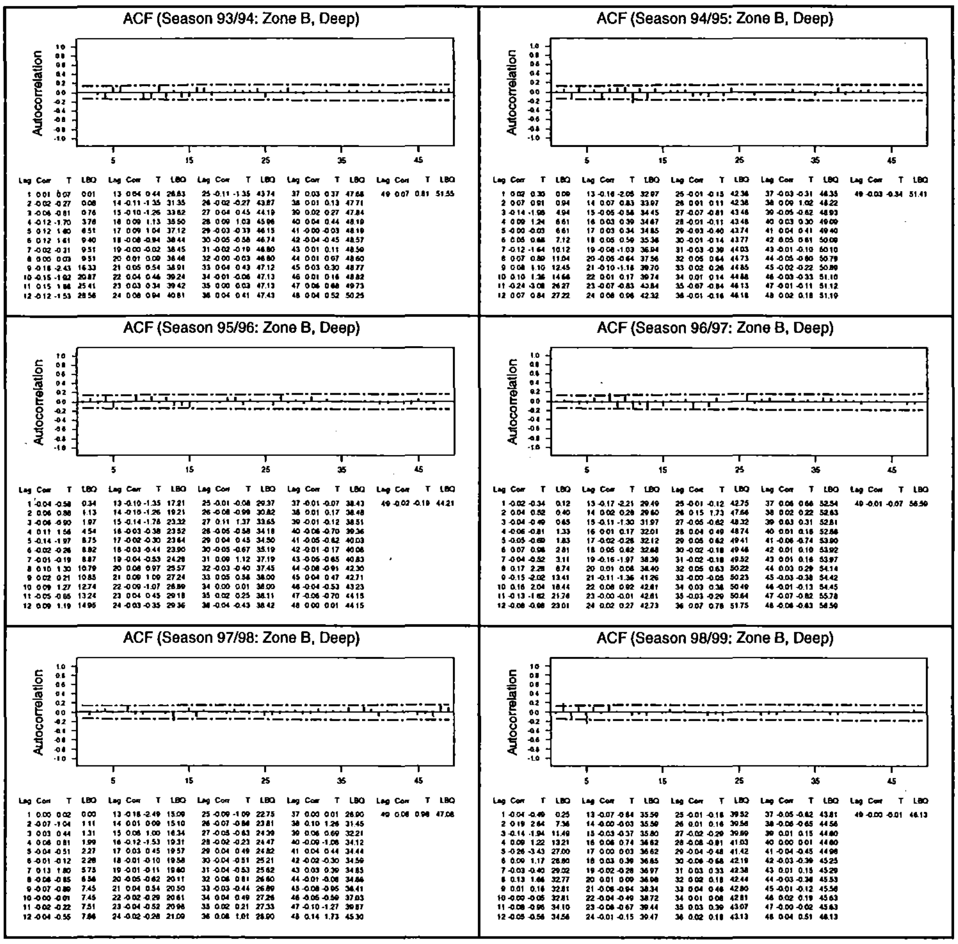


Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.16	1.41	2.08	8	0.08	0.59	26.89	15	0.10	0.64	29.08
2	-0.46	-3.87	18.71	9	0.08	0.51	27.40	16	-0.03	-0.17	29.15
3	-0.11	-0.82	19.75	10	-0.05	-0.36	27.66	17	-0.13	-0.86	30.81
4	0.26	1.86	25.36	11	-0.07	-0.47	28.10	18	-0.09	-0.58	31.60
5	-0.00	-0.02	25.36	12	0.01	0.07	28.11	19	0.02	0.13	31.65
6	-0.09	-0.64	26.11	13	0.03	0.18	28.18				
7	-0.04	-0.25	26.23	14	0.01	0.08	28.20				

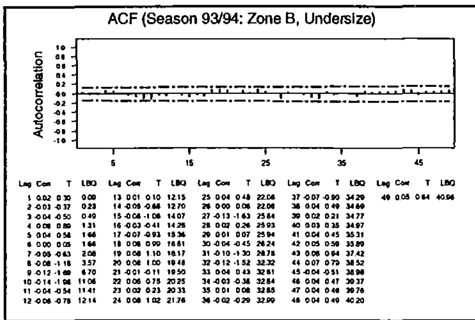
ACFs of the residuals from the models for shallow data sets in Zone B

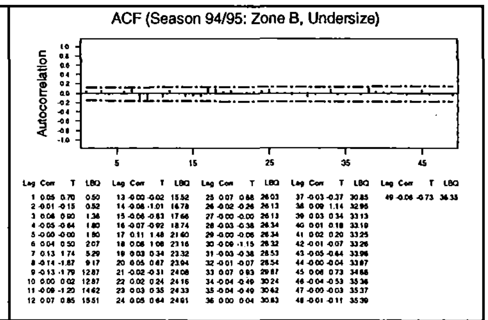


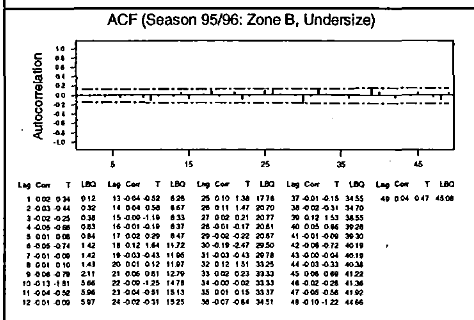
ACFs of the residuals from the models for deep data sets in Zone B

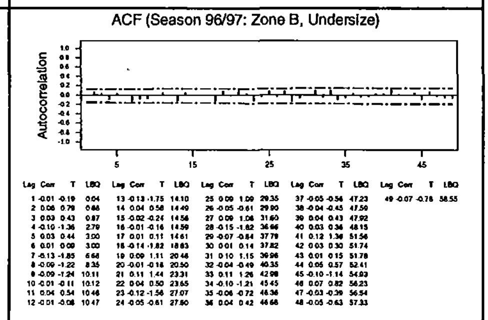


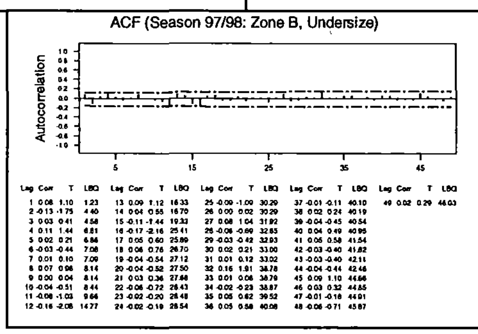
ACFs of the residuals from the models for undersized data sets in Zone B



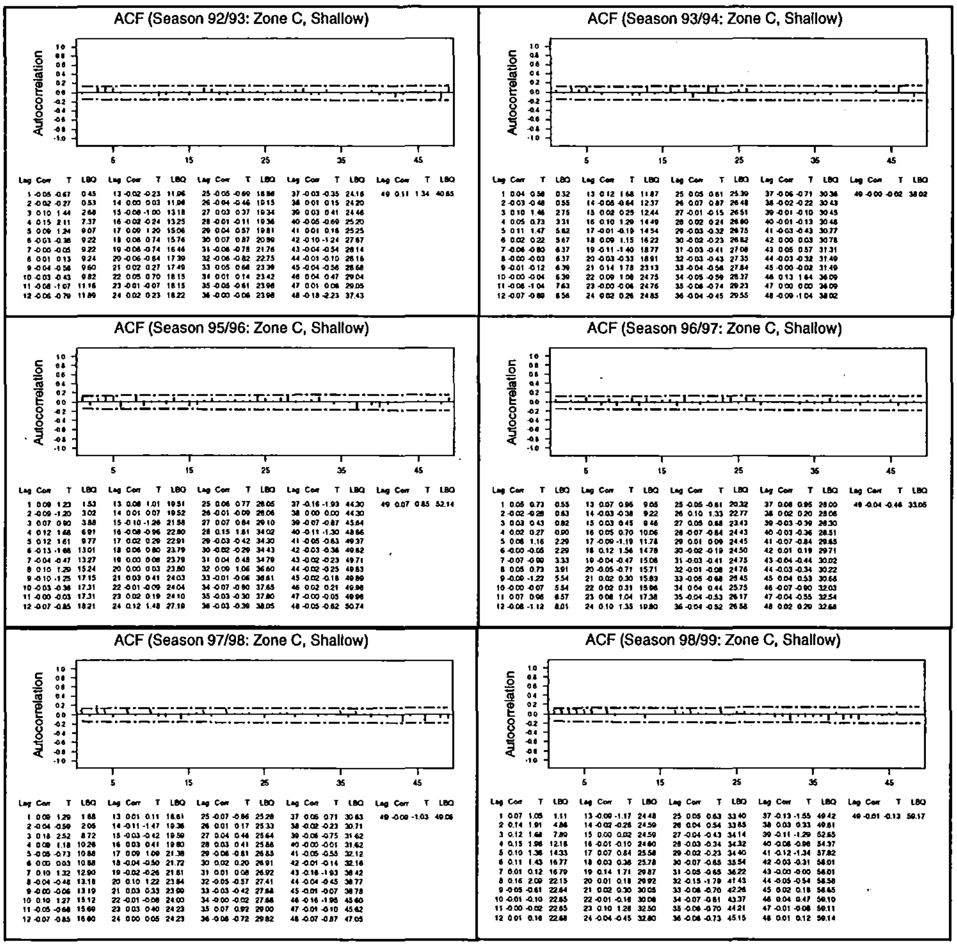




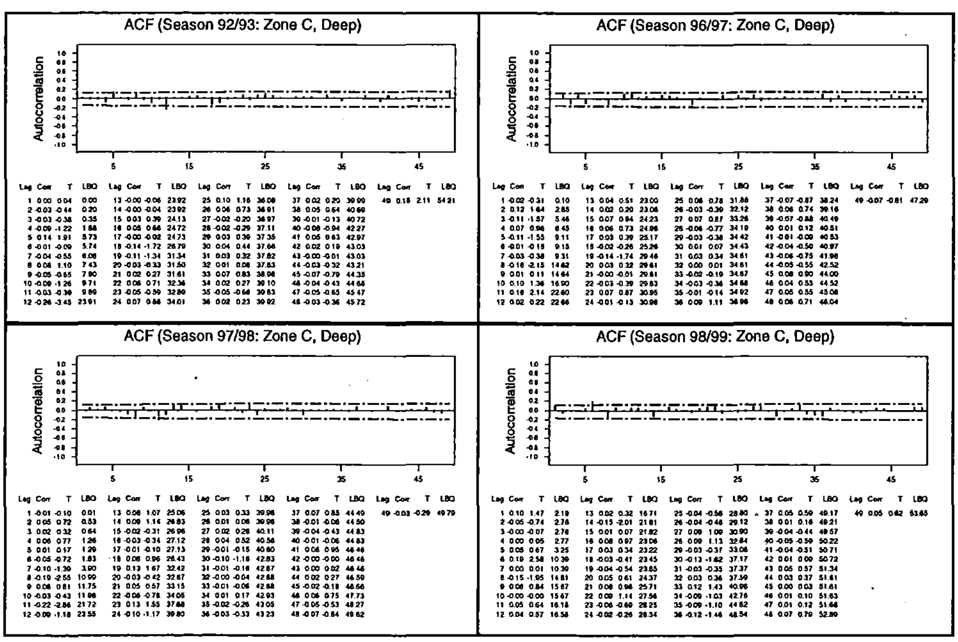




ACFs of the residuals from the models for shallow data sets in Zone C



ACFs of the residuals from the models for shallow data sets in Zone C



APPENDIX L: *SCA outputs for the transfer function models*

Season 92/93: Zone A, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 76

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9293ADP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
A9293DP	RANDOM	ORIGINAL	NONE
A9293SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1563	.0986	-1.59
2	V1	A9293SW	NUM.	1	1	NONE	.1386	.0671	2.07
3	THETA1	A9293DP	MA	1	1	NONE	-.7772	.0736	-10.56

```
TOTAL SUM OF SQUARES . . . . . . . .   0.875806E+01
TOTAL NUMBER OF OBSERVATIONS . . . .             76
RESIDUAL SUM OF SQUARES. . . . . . .   0.505386E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .             75
R-SQUARE . . . . . . . . . . . . . .          0.415
RESIDUAL VARIANCE ESTIMATE . . . . .   0.673848E-01
RESIDUAL STANDARD ERROR. . . . . . .   0.259586E+00
```

Season 92/93: Zone C, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9293CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9293SH	RANDOM	ORIGINAL	NONE
C9293SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.0995	.0390	-2.55
2	V1	C9293SW	NUM.	1	1	NONE	.1435	.0386	3.72
3	PHI1	C9293SH	D-AR	1	1	NONE	.3789	.0653	5.80

```
TOTAL SUM OF SQUARES . . . . . . . .   0.934186E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            196
RESIDUAL SUM OF SQUARES. . . . . . .   0.670830E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            194
R-SQUARE . . . . . . . . . . . . . .          0.275
RESIDUAL VARIANCE ESTIMATE . . . . .   0.345789E-01
RESIDUAL STANDARD ERROR. . . . . . .   0.185954E+00
```

Season 92/93: Zone C, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9293CDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9293DP	RANDOM	ORIGINAL	NONE
C9293SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1586	.0891	-1.78
2	V2	C9293SW	NUM.	1	2	NONE	.2155	.0822	2.62
3	PHI1	C9293DP	D-AR	1	1	NONE	.5205	.0618	8.42

TOTAL SUM OF SQUARES	0.422376E+02
TOTAL NUMBER OF OBSERVATIONS	196
RESIDUAL SUM OF SQUARES.	0.272621E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .	193
R-SQUARE	0.345
RESIDUAL VARIANCE ESTIMATE	0.141255E+00
RESIDUAL STANDARD ERROR.	0.375838E+00

Season 93/94: Zone A, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 76

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9394ADP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
A9394DP	RANDOM	ORIGINAL	NONE
A9394SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.0873	.0418	-2.09
2	V1	A9394SW	NUM.	1	1	NONE	.0638	.0309	2.06
3	THETA2	A9394DP	MA	1	2	NONE	.5284	.1026	5.15

TOTAL SUM OF SQUARES	0.510168E+01
TOTAL NUMBER OF OBSERVATIONS	76
RESIDUAL SUM OF SQUARES.	0.371500E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .	75
R-SQUARE	0.262
RESIDUAL VARIANCE ESTIMATE	0.495333E-01
RESIDUAL STANDARD ERROR.	0.222561E+00

Season 93/94: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9394BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9394SH	RANDOM	ORIGINAL	NONE
B9394SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1110	.0481	-2.31
2	V2	B9394SW	NUM.	1	2	NONE	.0932	.0333	2.80
3	THETA1	B9394SH	MA	1	1	NONE	.4087	.1357	3.01
4	PHI1	B9394SH	D-AR	1	1	NONE	.7416	.0987	7.51

```
TOTAL SUM OF SQUARES . . . . . . . .   0.924926E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            196
RESIDUAL SUM OF SQUARES. . . . . . .   0.664913E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            193
R-SQUARE . . . . . . . . . . . . . .          0.270
RESIDUAL VARIANCE ESTIMATE . . . . .   0.344514E-01
RESIDUAL STANDARD ERROR. . . . . . .   0.185611E+00
```

Season 93/94: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9394BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9394DP	RANDOM	ORIGINAL	NONE
B9394SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.3422	.1067	-3.21
2	V1	B9394SW	NUM.	1	1	NONE	.3129	.0858	3.65
3	PHI1	B9394DP	D-AR	1	1	NONE	.3276	.0678	4.83

```
TOTAL SUM OF SQUARES . . . . . . . .   0.614347E+02
TOTAL NUMBER OF OBSERVATIONS . . . .            196
RESIDUAL SUM OF SQUARES. . . . . . .   0.489059E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .            194
R-SQUARE . . . . . . . . . . . . . .          0.196
RESIDUAL VARIANCE ESTIMATE . . . . .   0.252092E+00
RESIDUAL STANDARD ERROR. . . . . . .   0.502088E+00
```

Season 93/94: Zone B, Undersize

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9394BUS

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9394US	RANDOM	ORIGINAL	NONE
B9394SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	.0857	.0529	1.62
2	V0	B9394SW	NUM.	1	0	NONE	-.0791	.0403	-1.96
3	PHI1	B9394US	D-AR	1	1	NONE	.4901	.0626	7.83

TOTAL SUM OF SQUARES	0.123336E+02
TOTAL NUMBER OF OBSERVATIONS	196
RESIDUAL SUM OF SQUARES.	0.948989E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .	195
R-SQUARE	0.227
RESIDUAL VARIANCE ESTIMATE	0.486661E-01
RESIDUAL STANDARD ERROR.	0.220604E+00

Season 93/94: Zone C, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9394CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9394SH	RANDOM	ORIGINAL	NONE
C9394SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1566	.0275	-5.70
2	V1	C9394SW	NUM.	1	1	NONE	.1602	.0250	6.42
3	PHI1	C9394SH	D-AR	1	1	NONE	.3167	.0679	4.66

TOTAL SUM OF SQUARES	0.584653E+01
TOTAL NUMBER OF OBSERVATIONS	196
RESIDUAL SUM OF SQUARES.	0.415201E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .	194
R-SQUARE	0.283
RESIDUAL VARIANCE ESTIMATE	0.214021E-01
RESIDUAL STANDARD ERROR.	0.146295E+00

Season 94/95: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9495BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9495SH	RANDOM	ORIGINAL	NONE
B9495SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1627	.0362	-4.50
2	V1	B9495SW	NUM.	1	1	NONE	.1547	.0268	5.78
3	PHI1	B9495SH	D-AR	1	1	NONE	.5653	.0587	9.63

```
TOTAL SUM OF SQUARES . . . . . . . .  0.776768E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.418699E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.455
RESIDUAL VARIANCE ESTIMATE . . . . .  0.215824E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.146909E+00
```

Season 94/95: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9495BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9495DP	RANDOM	ORIGINAL	NONE
B9495SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1641	.1024	-1.60
2	V1	B9495SW	NUM.	1	1	NONE	.1586	.0756	2.10
3	PHI1	B9495DP	D-AR	1	1	NONE	.5505	.0603	9.13

```
TOTAL SUM OF SQUARES . . . . . . . .  0.481145E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.334687E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.297
RESIDUAL VARIANCE ESTIMATE . . . . .  0.172519E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.415354E+00
```

Season 94/95: Zone B, Undersize

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THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN   1  THRU  196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9495BUS

 ---------------------------------------------------------------------
 VARIABLE    TYPE OF    ORIGINAL     DIFFERENCING
             VARIABLE   OR CENTERED

 B9495US     RANDOM     ORIGINAL     NONE

 B9495SW     RANDOM     ORIGINAL     NONE
 ---------------------------------------------------------------------

  PARAMETER   VARIABLE  NUM./  FACTOR  ORDER  CONS-     VALUE      STD     T
   LABEL        NAME    DENOM.                TRAINT              ERROR  VALUE

  1  CONST              CNST      1      0    NONE      .1030     .0335   3.07
  2    V0    B9495SW    NUM.      1      0    NONE     -.1024     .0279  -3.67
  3   PHI1   B9495US    D-AR      1      1    NONE      .3611     .0675   5.35

 TOTAL SUM OF SQUARES . . . . . . . .  0.639946E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .           196
 RESIDUAL SUM OF SQUARES. . . . . . .  0.536054E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .           195
 R-SQUARE . . . . . . . . . . . . . .         0.158
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.274899E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.165801E+00
```

Season 95/96: Zone A, Deep

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN   1  THRU   76

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596ADP

 ---------------------------------------------------------------------
 VARIABLE    TYPE OF    ORIGINAL     DIFFERENCING
             VARIABLE   OR CENTERED

 A9596DP     RANDOM     ORIGINAL     NONE

 A9596SW     RANDOM     ORIGINAL     NONE
 ---------------------------------------------------------------------

  PARAMETER   VARIABLE  NUM./  FACTOR  ORDER  CONS-     VALUE      STD     T
   LABEL        NAME    DENOM.                TRAINT              ERROR  VALUE

  1  CONST              CNST      1      0    NONE     -.1456     .0326  -4.47
  2    V1    A9596SW    NUM.      1      1    NONE      .1172     .0244   4.80

 TOTAL SUM OF SQUARES . . . . . . . .  0.140369E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .            76
 RESIDUAL SUM OF SQUARES. . . . . . .  0.107065E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .            75
 R-SQUARE . . . . . . . . . . . . . .         0.227
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.142754E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.119480E+00
```

Season 95/96: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 197

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9596SH	RANDOM	ORIGINAL	NONE
B9596SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1230	.0380	-3.24
2	V1	B9596SW	NUM.	1	1	NONE	.1143	.0229	5.00
3	THETA1	B9596SH	MA	1	1	NONE	.2812	.1035	2.72
4	PHI1	B9596SH	D-AR	1	1	NONE	.7641	.0664	11.51

```
TOTAL SUM OF SQUARES . . . . . . . .  0.606126E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           197
RESIDUAL SUM OF SQUARES. . . . . . .  0.340649E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           195
R-SQUARE . . . . . . . . . . . . . .         0.432
RESIDUAL VARIANCE ESTIMATE . . . . .  0.174692E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.132171E+00
```

Season 95/96: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 197

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9596DP	RANDOM	ORIGINAL	NONE
B9596SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.2378	.0845	-2.81
2	V2	B9596SW	NUM.	1	2	NONE	.2277	.0746	3.05
3	PHI1	B9596DP	D-AR	1	1	NONE	.2564	.0695	3.69

```
TOTAL SUM OF SQUARES . . . . . . . .  0.486159E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           197
RESIDUAL SUM OF SQUARES. . . . . . .  0.410487E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.143
RESIDUAL VARIANCE ESTIMATE . . . . .  0.211591E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.459991E+00
```

Season 95/96: Zone B, Undersize

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 197

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596BUS

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9596US	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	.38251E-04	.0249	.2E-02
2	PHI1	B9596US	D-AR	1	1	NONE	.4303	.0640	6.72

```
TOTAL SUM OF SQUARES . . . . . . . .  0.961338E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           197
RESIDUAL SUM OF SQUARES. . . . . . .  0.770262E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           196
R-SQUARE . . . . . . . . . . . . . .         0.195
RESIDUAL VARIANCE ESTIMATE . . . . .  0.392991E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.198240E+00
```

Season 95/96: Zone C, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 197

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9596SH	RANDOM	ORIGINAL	NONE
C9596SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1619	.0376	-4.30
2	V1	C9596SW	NUM.	1	1	NONE	.1800	.0329	5.47
3	PHI1	C9596SH	D-AR	1	1	NONE	.4934	.0620	7.96

```
TOTAL SUM OF SQUARES . . . . . . . .  0.936240E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           197
RESIDUAL SUM OF SQUARES. . . . . . .  0.590562E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           195
R-SQUARE . . . . . . . . . . . . . .         0.363
RESIDUAL VARIANCE ESTIMATE . . . . .  0.302852E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.174026E+00
```

Season 95/96: Zone C, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 197

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9596CDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9596DP	RANDOM	ORIGINAL	NONE
C9596SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1416	.0595	-2.38
2	V1	C9596SW	NUM.	1	1	NONE	.1628	.0554	2.94
3	THETA1	C9596DP	MA	1	1	NONE	-.1926	.0696	-2.77
4	THETA2	C9596DP	MA	1	2	NONE	-.3345	.0716	-4.67

```
TOTAL SUM OF SQUARES . . . . . . . .  0.233615E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           197
RESIDUAL SUM OF SQUARES. . . . . . .  0.210742E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           196
R-SQUARE . . . . . . . . . . . . . .         0.093
RESIDUAL VARIANCE ESTIMATE . . . . .  0.107522E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.327905E+00
```

Season 96/97: Zone A, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 76

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697ADP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
A9697DP	RANDOM	ORIGINAL	NONE
A9697SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1851	.0729	-2.54
2	V1	A9697SW	NUM.	1	1	NONE	.1244	.0497	2.51
3	THETA1	A9697DP	MA	1	1	NONE	-.3390	.1122	-3.02

```
TOTAL SUM OF SQUARES . . . . . . . .  0.517918E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            76
RESIDUAL SUM OF SQUARES. . . . . . .  0.414568E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            75
R-SQUARE . . . . . . . . . . . . . .         0.189
RESIDUAL VARIANCE ESTIMATE . . . . .  0.552757E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.235108E+00
```

Season 96/97: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9697SH	RANDOM	ORIGINAL	NONE
B9697SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.2088	.0514	-4.06
2	V0	B9697SW	NUM.	1	0	NONE	-.0704	.0299	-2.36
3	V1	B9697SW	NUM.	1	1	NONE	.1996	.0306	6.51
4	V2	B9697SW	NUM.	1	2	NONE	.0662	.0299	2.22
5	PHI1	B9697SH	D-AR	1	1	NONE	.5789	.0589	9.84

```
TOTAL SUM OF SQUARES . . . . . . . .   0.958393E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            196
RESIDUAL SUM OF SQUARES. . . . . . .   0.481894E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            193
R-SQUARE . . . . . . . . . . . . . .          0.489
RESIDUAL VARIANCE ESTIMATE . . . . .   0.249686E-01
RESIDUAL STANDARD ERROR. . . . . . .   0.158015E+00
```

Season 96/97: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9697DP	RANDOM	ORIGINAL	NONE
B9697SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1879	.0980	-1.92
2	V1	B9697SW	NUM.	1	1	NONE	.1617	.0821	1.97
3	PHI1	B9697DP	D-AR	1	1	NONE	.3799	.0664	5.72

```
TOTAL SUM OF SQUARES . . . . . . . .   0.557406E+02
TOTAL NUMBER OF OBSERVATIONS . . . .            196
RESIDUAL SUM OF SQUARES. . . . . . .   0.450680E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .            194
R-SQUARE . . . . . . . . . . . . . .          0.183
RESIDUAL VARIANCE ESTIMATE . . . . .   0.232309E+00
RESIDUAL STANDARD ERROR. . . . . . .   0.481985E+00
```

Season 96/97: Zone B, Undersize

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697BUS

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9697US	RANDOM	ORIGINAL	NONE
B9697SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.0083	.0431	-.19
2	V0	B9697SW	NUM.	1	0	NONE	-.1246	.0339	-3.67
3	V1	B9697SW	NUM.	1	1	NONE	.1210	.0339	3.57
4	PHI1	B9697US	D-AR	1	1	NONE	.4223	.0648	6.52

```
TOTAL SUM OF SQUARES . . . . . . . .  0.864502E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.628638E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.265
RESIDUAL VARIANCE ESTIMATE . . . . .  0.324040E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.180011E+00
```

Season 96/97: Zone C, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9697SH	RANDOM	ORIGINAL	NONE
C9697SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1987	.0334	-5.95
2	V1	C9697SW	NUM.	1	1	NONE	.2107	.0303	6.96
3	PHI1	C9697SH	D-AR	1	1	NONE	.4059	.0654	6.21

```
TOTAL SUM OF SQUARES . . . . . . . .  0.971245E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.580697E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.396
RESIDUAL VARIANCE ESTIMATE . . . . .  0.299328E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.173011E+00
```

Season 96/97: Zone C, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9697CDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9697DP	RANDOM	ORIGINAL	NONE
C9697SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1614	.0597	-2.71
2	V1	C9697SW	NUM.	1	1	NONE	.1535	.0546	2.81
3	THETA1	C9697DP	MA	1	1	NONE	.4622	.1772	2.61
4	PHI1	C9697DP	D-AR	1	1	NONE	.6265	.1495	4.19

```
TOTAL SUM OF SQUARES . . . . . . . .  0.266195E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.226349E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.141
RESIDUAL VARIANCE ESTIMATE . . . . .  0.116675E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.341577E+00
```

Season 97/98: Zone A, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 76

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798ADP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
A9798DP	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	.0282	.0342	.83
2	THETA1	A9798DP	MA	1	1	NONE	-.6275	.0946	-6.63

```
TOTAL SUM OF SQUARES . . . . . . . .  0.369382E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            76
RESIDUAL SUM OF SQUARES. . . . . . .  0.267759E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            76
R-SQUARE . . . . . . . . . . . . . .         0.275
RESIDUAL VARIANCE ESTIMATE . . . . .  0.352314E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.187700E+00
```

Season 97/98: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9798SH	RANDOM	ORIGINAL	NONE
B9798SW	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1012	.0425	-2.38
2	V1	B9798SW	NUM.	1	1	NONE	.0940	.0299	3.14
3	PHI1	B9798SH	D-AR	1	1	NONE	.5966	.0577	10.35

```
TOTAL SUM OF SQUARES . . . . . . . .  0.791915E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.490379E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.374
RESIDUAL VARIANCE ESTIMATE . . . . .  0.252773E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.158988E+00
```

Season 97/98: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9798DP	RANDOM	ORIGINAL	NONE

PARAMETER	LABEL	VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.0210	.0546	-.38
2	PHI1	B9798DP	D-AR	1	1	NONE	.5762	.0576	10.00

```
TOTAL SUM OF SQUARES . . . . . . . .  0.325996E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.206127E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           195
R-SQUARE . . . . . . . . . . . . . .         0.364
RESIDUAL VARIANCE ESTIMATE . . . . .  0.105706E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.325124E+00
```

Season 97/98: Zone B, Undersize

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798BUS

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9798US	RANDOM	ORIGINAL	NONE
B9798SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	.1093	.0378	2.89
2	V0	B9798SW	NUM.	1	0	NONE	-.1073	.0296	-3.62
3	PHI1	B9798US	D-AR	1	1	NONE	.4327	.0643	6.73

```
TOTAL SUM OF SQUARES . . . . . . . .  0.718549E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.545811E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           195
R-SQUARE . . . . . . . . . . . . . .         0.237
RESIDUAL VARIANCE ESTIMATE . . . . .  0.279903E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.167303E+00
```

Season 97/98: Zone C, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798CSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9798SH	RANDOM	ORIGINAL	NONE
C9798SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1128	.0365	-3.09
2	V1	C9798SW	NUM.	1	1	NONE	.1800	.0224	8.03
3	V2	C9798SW	NUM.	1	2	NONE	-.0616	.0225	-2.74
4	PHI1	C9798SH	D-AR	1	1	NONE	.6089	.0564	10.80

```
TOTAL SUM OF SQUARES . . . . . . . .  0.626276E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.293707E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           193
R-SQUARE . . . . . . . . . . . . . .         0.524
RESIDUAL VARIANCE ESTIMATE . . . . .  0.152180E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.123361E+00
```

Season 97/98: Zone C, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9798CDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
C9798DP	RANDOM	ORIGINAL	NONE
C9798SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1795	.0752	-2.39
2	V1	C9798SW	NUM.	1	1	NONE	.1800	.0611	2.94
3	PHI1	C9798DP	D-AR	1	1	NONE	.5166	.0611	8.45

```
TOTAL SUM OF SQUARES . . . . . . . .  0.318284E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.220688E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.299
RESIDUAL VARIANCE ESTIMATE . . . . .  0.113757E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.337278E+00
```

Season 98/99: Zone A, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 74

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899ADP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
A9899DP	RANDOM	ORIGINAL	NONE
A9899SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS-TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.0479	.0932	-.51
2	V0	A9899SW	NUM.	1	0	NONE	.0493	.0775	.64
3	V1	A9899SW	NUM.	1	1	NONE	.0887	.0938	.95
4	V2	A9899SW	NUM.	1	2	NONE	-.1053	.0783	-1.34
5	PHI1	A9899DP	D-AR	1	1	NONE	.0871	.1186	.73

```
TOTAL SUM OF SQUARES . . . . . . . .  0.503865E+01
TOTAL NUMBER OF OBSERVATIONS . . . .            74
RESIDUAL SUM OF SQUARES. . . . . . .  0.475780E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .            71
R-SQUARE . . . . . . . . . . . . . .         0.016
RESIDUAL VARIANCE ESTIMATE . . . . .  0.670113E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.258865E+00
```

Season 98/99: Zone B, Shallow

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899BSH

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9899SH	RANDOM	ORIGINAL	NONE
B9899SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.1283	.0395	-3.25
2	V1	B9899SW	NUM.	1	1	NONE	.1311	.0247	5.31
3	PHI1	B9899SH	D-AR	1	1	NONE	.6858	.0525	13.07

```
TOTAL SUM OF SQUARES . . . . . . . .  0.776481E+01
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.370054E+01
EFFECTIVE NUMBER OF OBSERVATIONS . .           194
R-SQUARE . . . . . . . . . . . . . .         0.519
RESIDUAL VARIANCE ESTIMATE . . . . .  0.190750E-01
RESIDUAL STANDARD ERROR. . . . . . .  0.138112E+00
```

Season 98/99: Zone B, Deep

THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN 1 THRU 196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899BDP

VARIABLE	TYPE OF VARIABLE	ORIGINAL OR CENTERED	DIFFERENCING
B9899DP	RANDOM	ORIGINAL	NONE
B9899SW	RANDOM	ORIGINAL	NONE

PARAMETER LABEL		VARIABLE NAME	NUM./ DENOM.	FACTOR	ORDER	CONS- TRAINT	VALUE	STD ERROR	T VALUE
1	CONST		CNST	1	0	NONE	-.2073	.0910	-2.28
2	V1	B9899SW	NUM.	1	1	NONE	.2165	.0768	2.82
3	THETA1	B9899DP	MA	1	1	NONE	-.2935	.0703	-4.17
4	THETA2	B9899DP	MA	1	2	NONE	-.2530	.0706	-3.59

```
TOTAL SUM OF SQUARES . . . . . . . .  0.511661E+02
TOTAL NUMBER OF OBSERVATIONS . . . .           196
RESIDUAL SUM OF SQUARES. . . . . . .  0.425313E+02
EFFECTIVE NUMBER OF OBSERVATIONS . .           195
R-SQUARE . . . . . . . . . . . . . .         0.164
RESIDUAL VARIANCE ESTIMATE . . . . .  0.218109E+00
RESIDUAL STANDARD ERROR. . . . . . .  0.467022E+00
```

Season 98/99: Zone C, Shallow

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN    1  THRU  196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899CSH

 -----------------------------------------------------------------------
 VARIABLE    TYPE OF     ORIGINAL      DIFFERENCING
             VARIABLE   OR CENTERED

 C9899SH     RANDOM      ORIGINAL      NONE

 C9899SW     RANDOM      ORIGINAL      NONE
 -----------------------------------------------------------------------

  PARAMETER   VARIABLE  NUM./  FACTOR  ORDER   CONS-      VALUE       STD      T
    LABEL       NAME    DENOM.                 TRAINT                ERROR   VALUE

   1  CONST             CNST      1      0     NONE      -.1799      .0318   -5.66
   2    V1    C9899SW   NUM.      1      1     NONE       .2144      .0246    8.72
   3  THETA1  C9899SH    MA       1      1     NONE       .5392      .1210    4.46
   4   PHI1   C9899SH   D-AR      1      1     NONE       .8194      .0820    9.99

 TOTAL SUM OF SQUARES . . . . . . . .  0.601947E+01
 TOTAL NUMBER OF OBSERVATIONS . . . .           196
 RESIDUAL SUM OF SQUARES. . . . . . .  0.343323E+01
 EFFECTIVE NUMBER OF OBSERVATIONS . .           194
 R-SQUARE . . . . . . . . . . . . . .         0.424
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.176970E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.133030E+00
```

Season 98/99: Zone C, Deep

```
THE FOLLOWING ANALYSIS IS BASED ON TIME SPAN    1  THRU  196

SUMMARY FOR UNIVARIATE TIME SERIES MODEL -- M9899CDP

 -----------------------------------------------------------------------
 VARIABLE    TYPE OF     ORIGINAL      DIFFERENCING
             VARIABLE   OR CENTERED

 C9899DP     RANDOM      ORIGINAL      NONE

 C9899SW     RANDOM      ORIGINAL      NONE
 -----------------------------------------------------------------------

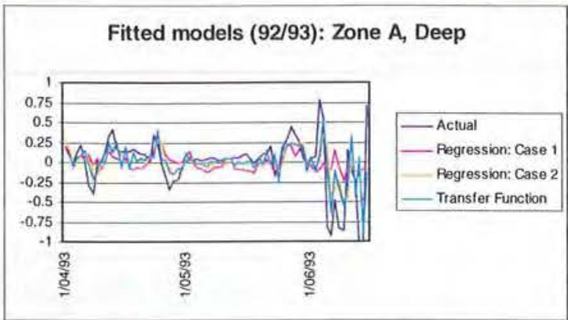
  PARAMETER   VARIABLE  NUM./  FACTOR  ORDER   CONS-      VALUE       STD      T
    LABEL       NAME    DENOM.                 TRAINT                ERROR   VALUE

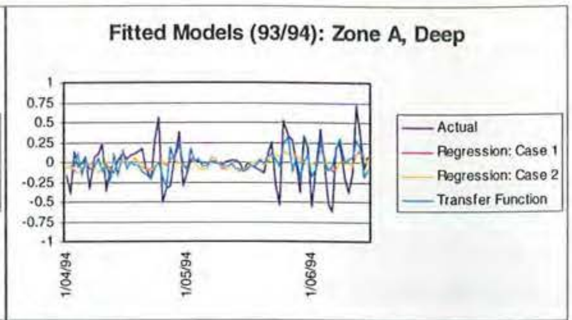
   1  CONST             CNST      1      0     NONE      -.2949      .0545   -5.41
   2    V1    C9899SW   NUM.      1      1     NONE       .3607      .0564    6.40
   3   PHI1   C9899DP   D-AR      1      1     NONE       .2225      .0700    3.18

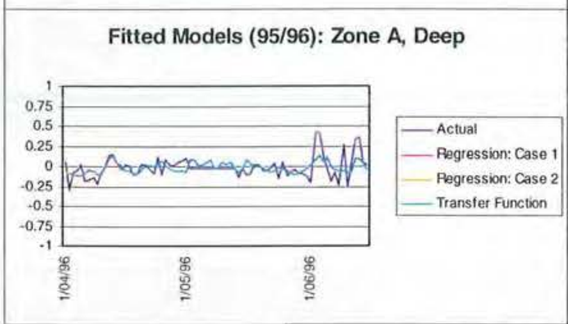
 TOTAL SUM OF SQUARES . . . . . . . .  0.250898E+02
 TOTAL NUMBER OF OBSERVATIONS . . . .           196
 RESIDUAL SUM OF SQUARES. . . . . . .  0.183939E+02
 EFFECTIVE NUMBER OF OBSERVATIONS . .           194
 R-SQUARE . . . . . . . . . . . . . .         0.259
 RESIDUAL VARIANCE ESTIMATE . . . . .  0.948139E-01
 RESIDUAL STANDARD ERROR. . . . . . .  0.307919E+00
```

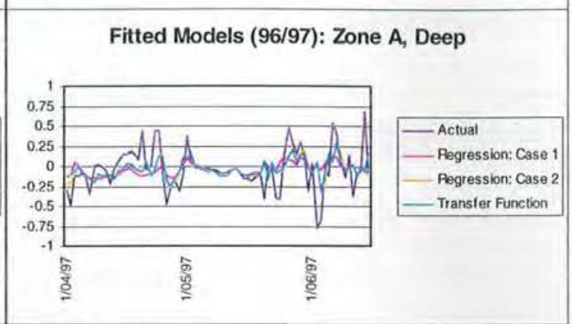
APPENDIX M: *Fits compared with Actual values*

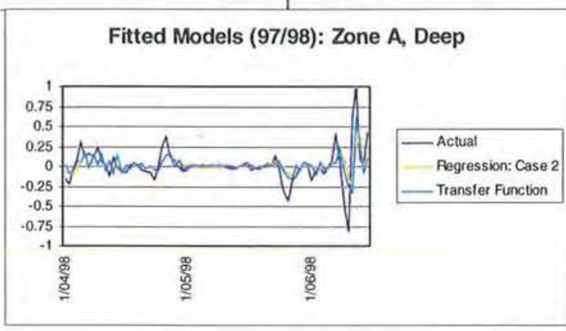
Graphs for deep data sets in Zone A



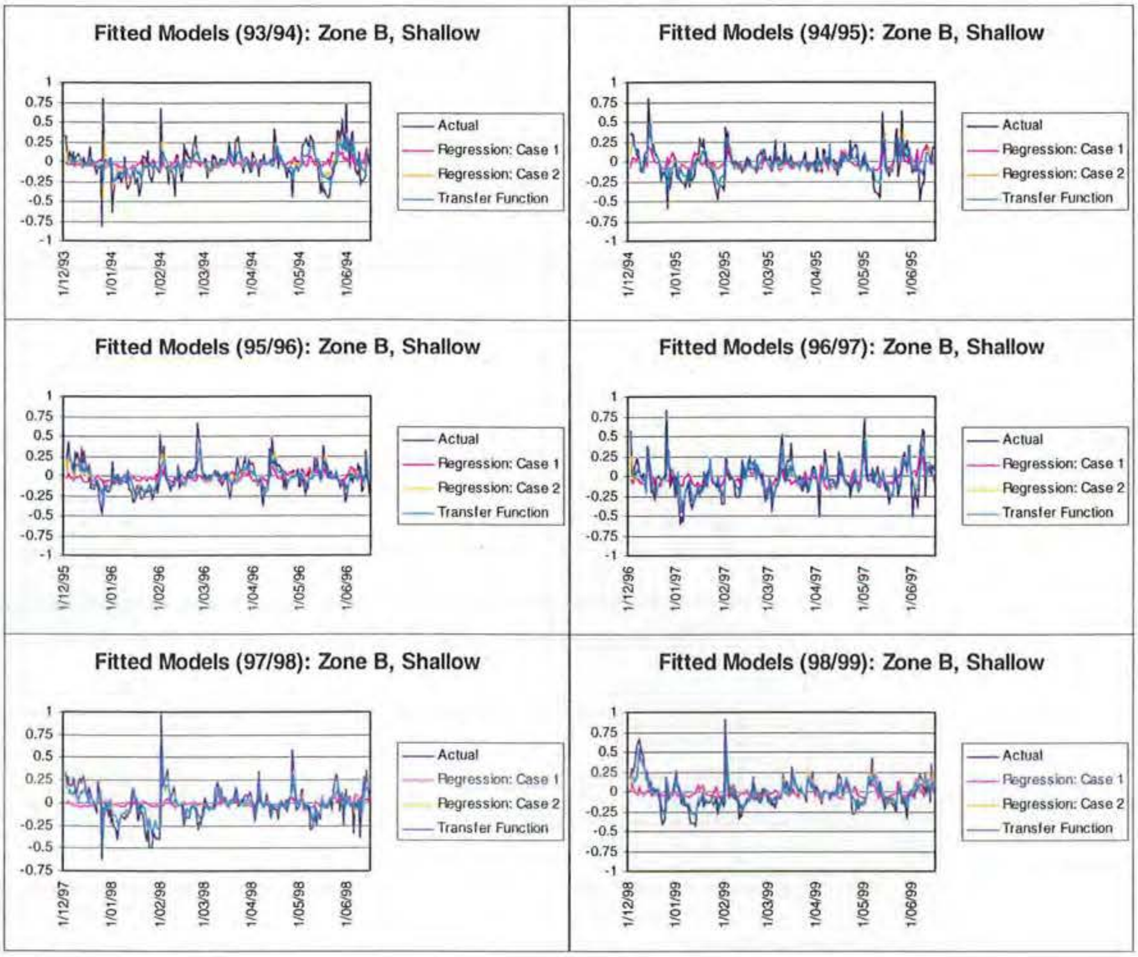




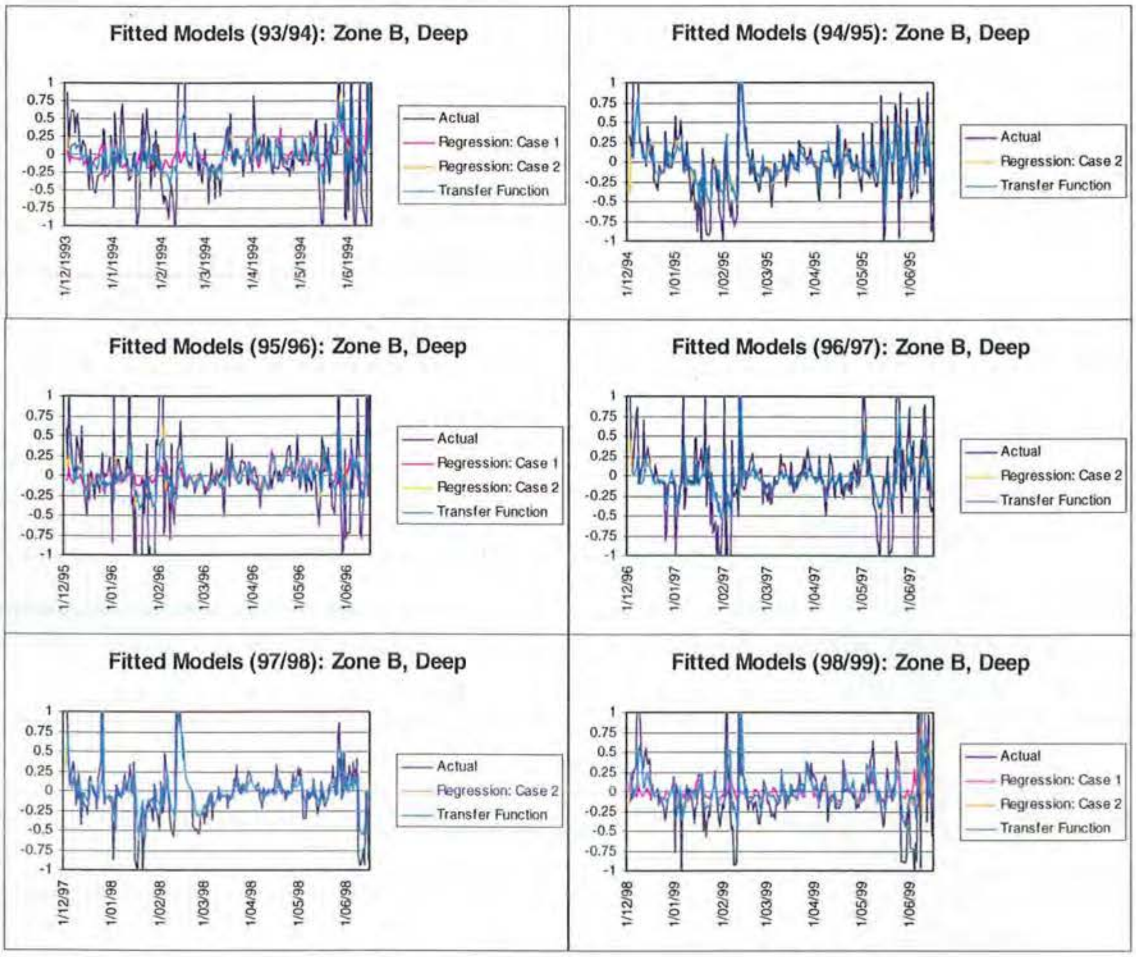




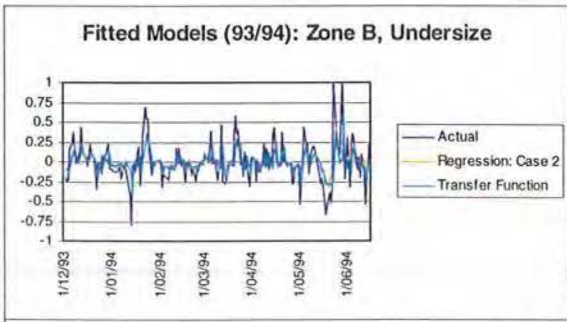
Graphs for shallow data sets in Zone B

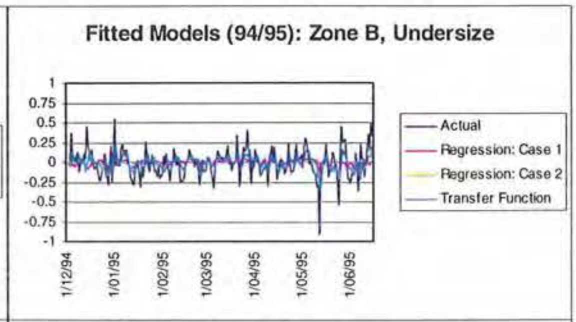


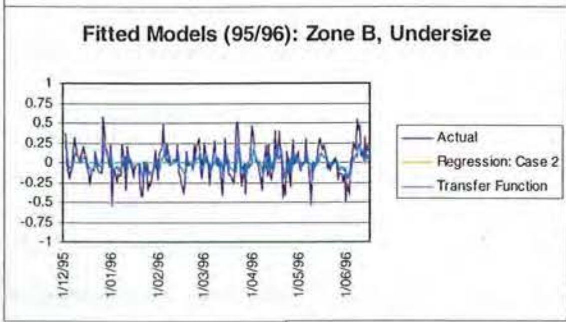
Graphs for deep data sets in Zone B

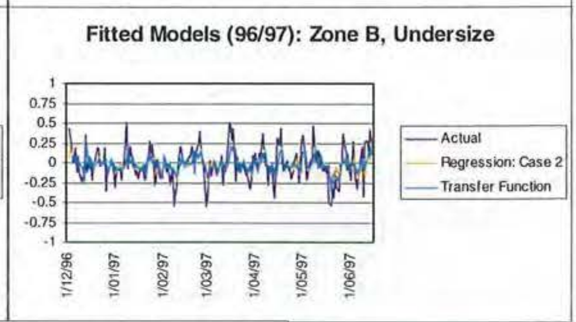


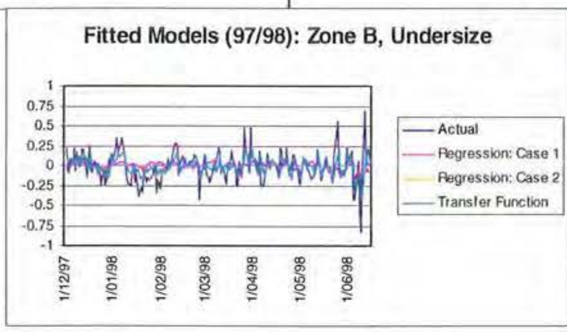
Graphs for undersized data sets in Zone B



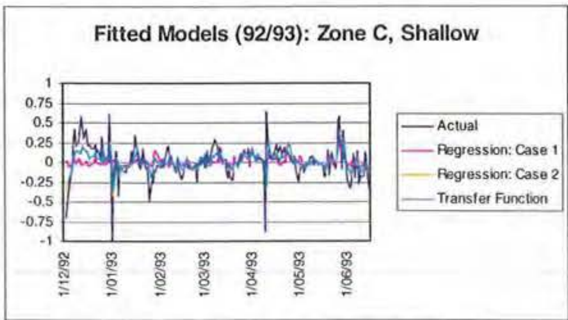


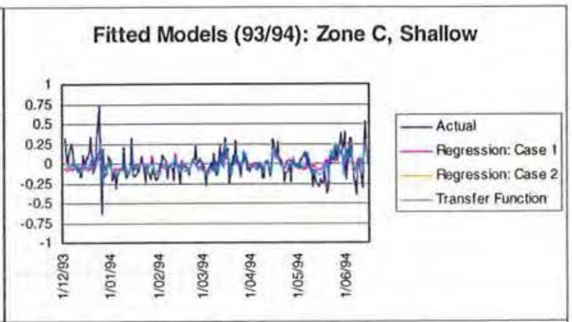


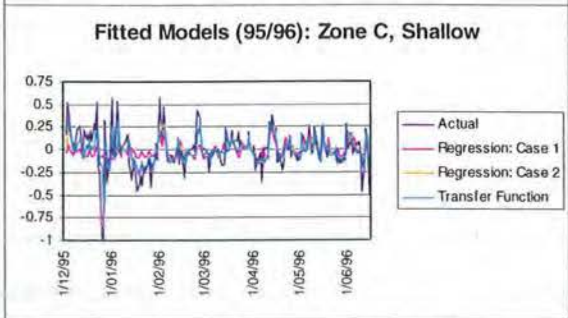


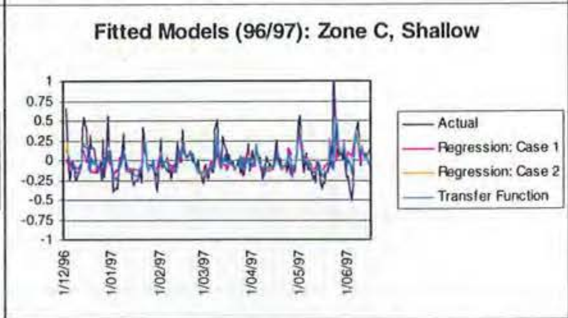


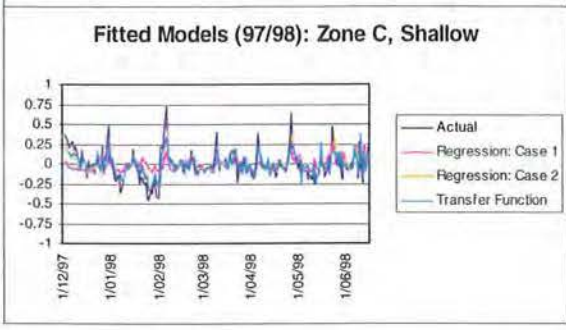
Graphs for shallow data sets in Zone C

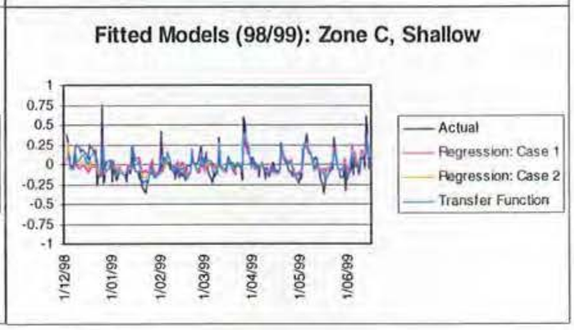












Graphs for deep data sets in Zone C